Comparing nuclear trajectories in Germany and the United Kingdom: from regimes to democracies in sociotechnical transitions and discontinuities

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Abstract

This paper focuses on the starkly differing nuclear policies of Germany and the UK. Germany has committed to discontinue nuclear power, aiming to phase the technology out by 2022. The UK has long professed the aim of a 'nuclear renaissance', promoting the most ambitious nuclear construction programme in Europe. The present analysis of this contrast is based around a simple yet fundamental question: which aspects contribute most to producing such divergent energy developments in these two countries? Distinguishing possible interpretive dimensions that are relatively 'internal' or 'external' to the main foci of attention in sociotechnical transitions theory, we develop a novel set of criteria spanning technical, economic, resource-based and political issues. Under each, we ask whether specific characteristics of either national setting would tend to make the phase out of nuclear power more or less likely. Our findings are that 'internal' aspects tend to predict discontinuity to be more likely in the UK than Germany. Only 'external' aspects clearly predict the actual trend. We argue on this basis that sociotechnical discontinuity is rather poorly explained by reference to the circumscribed concepts highlighted in conventional narrow versions of transitions theory. What is evidently more important, are wider political factors relating broadly to general 'qualities of democracy'.

1. Introduction

This paper is based around a simple yet under-explored query in research on Sustainability Transitions (ST) and socio-technical change: why do countries that are fairly similar in terms of development, wealth, size and existing energy portfolios, undertake such different pathways towards energy sustainability? This paper explores this question by examining perhaps the most starkly differing directions for 'sustainable' energy strategies in the 'developed' world: Germany and the UK. Following the Fukushima nuclear disaster in 2011 Germany confirmed a complex shift towards a decentralised low carbon energy system involving the phasing out of nuclear power by 2022 (1). This is an ongoing commitment, rather than a realised end. But it is precisely in this role as a firmly committed strategy, that the contrast is most pronounced with the contrasting commitment in the UK, concerning equally as-yet-unrealised plans to undertake a low carbon energy transition involving the most ambitious nuclear new build programme in Europe (2,3). These differing decisions have been reinforced since the immediate post-Fukushima decisions: with Germany on schedule in its reactor shut down plans (4) and the UK government sustaining policy support for new nuclear (5,6). This is despite costs of UK low carbon alternatives like offshore wind now being substantially below those of nuclear power (7–9).

With the Fukushima disaster in Japan constituting (in the language of sociotechnical transitions) an external landscape "shock" (10), the starting point here lies beneath the detailed particularities of recent nuclear developments in Germany and the UK. Instead, the focus is on the strikingly different nuclear policy responses to this same general shock, set in the same global context, across each of these two countries (11). With a pre-Fukushima nuclear portfolio of 17 reactors producing a quarter of domestic electricity, Germany made a decision to close of 8 reactors immediately and undertake a complete nuclear phase-out by 2022 (1). With 17 generally smaller reactors comprising only 18% of a smaller national electricity system, the UK reaffirmed its pre-Fukushima commitment to construct around 16 GWe of new nuclear capacity by 2030, with potential for a total of 19 GWe after that (12). This paper asks what it is that drives such differing energy pathways.

There is much discussion over the particular course of events in these two countries following the Fukushima disaster, which might help illuminate why such different policy orientations emerged (13–15). For example, the timing of regional elections in Germany may have been a proximate motivating factor – with Angela Merkel vulnerable to losing votes if she did not reaffirm a prior nuclear phase out (13). A divergent salient factor in the UK, lies in close collaboration in the Fukushima aftermath between policy makers and industry to maintain a positive spin around nuclear (16). Rather than selecting specific explanatory storylines however, we are interested in more systematic interrogation of these contrasting post-Fukushima decisions, grounded in a broader long-run picture of trends and pressures across a range of economic, political, and technical issues.

For a start, this requires going beyond the 'political pyrolysis' of reducing multidimensional political issues to an ostensibly simple singular technical focus disproportionately on carbon (17). Ambitions towards radical carbon emissions reductions both in Germany (1,18) and the UK (19) help foster this frequent over-reduction in much contemporary energy policy analysis (20). But it implies no diminishing of zero carbon energy imperatives, to acknowledge that success or failure in such a massive, complex, systemic long-term political-economic-cultural endeavour, should not be reduced merely to month-by-month emissions statistics. In any case, similar national commitments in the two countries, mean differing approaches cannot simply be explained in terms of contrasting intensities in stated low carbon policy goals. Scrutiny must be political not just technical, attending to ambiguous and contested diversities of pathways towards sustainability (21).

To understand possible drivers, we build on a wide body of research concerned with: (1) 'sectoral innovation systems' (22,23), burgeoning analyses of 'sustainability transitions' (24) and the particular approach known as socio-technical regime theory (25,26)(27). By reference to these literatures, we develop a set of 9 criteria constituted by 29 parameters reflecting aspects that might variously be considered 'internal' or 'external' to the focal attention of these theories. We also draw on important insights from literatures specifically on nuclear power (28–33), to produce from empirical analysis, a series of propostions in relation to each criterion concerning (to the extent possible) whether discontinuation thereby appears more likely in the UK or Germany.

The paper proceeds as follows. In Section 2, we introduce key literatures offering a basis for the present analytical framework. The main part of the paper is Section 3, where we discuss the evidence in each case study country bearing on whether nuclear discontinuation might reasonably be thought more or less likely under each parameter. In Section 4 we discuss the general implications that arise from these analyses. In short, what we find is that for 'internal' aspects (relating to economic conditions, strength of respective nuclear industries and resource potentials for rival 'niche' technologies), nuclear discontinuation seems clearly more likely in the UK than Germany. This is the opposite of the actual picture. Evidently more salient are aspects that are relatively external to these theories, relating to wider institutionl structures beyond the focal regime and contending niches, like political cultures, non-energy policy related interests and the general qualities of 'democracy'. It is these that make nuclear discontinuation more likely in Germany than the UK. Indeed, it seems these 'external' aspects have *overridden* the outcome that would otherwise have been made more likely by the 'internal' aspects conventionally highlighted in sociotechnical transitions theory.

2. Background literature and analytical approach

As already discussed, this analysis builds on research relating to 'sectoral innovation systems' (22), 'sustainability transitions' (24) and what might broadly be understood as socio-technical regime theory (25). Taken together, it is this broad literature that forms the main foundations in current policy-relevant understandings concerning the bringing about of 'regime shifts' in technological systems (34). It is widely recognised here that Germany's aims to move from a centralised energy system including nuclear power to a decentralised renewables-based system represents an example of a 'regime shift' (35). UK policy contrasts here, in supporting greater 'energy regime' continuity, including sustained commitment to centralised nuclear plant (36).

Central to such 'regime-theoretic' approaches are ideas that technological change entails co-evolutionary interactions between technological artefacts, governance institutions, and social agents. Over time, innovative 'niche' technologies diffuse, transform and stabilise around what might be termed (despite various vocabularies) 'the regime' (34). Through this process, new regimes arise, with differing sets of artefacts, rules and regulations becoming apparent (37). Much has been written on how processes of nurturing and empowerment can – alongside relevant contextual features of 'the landscape' (27) – support 'diffusion' of niches to 'destabilise' existing socio-technical regimes (34,38–40).

Interest has increasingly focused at this 'regime level' in order to understand how 'stability' is in these terms variously maintained or undermined (36,37,41–47). It is thereby processes operating around this immediate explanatory context that form the 'primary' focus in much sociotechnical transitions analysis. We refer to this focal context as the 'focal regime/niche configuration'. Aspects generally highlighted in this context are effectively 'internal' to prevailing regime theory (27). Below, we develop five criteria in this regard, relating to various economic, technical, engineering and innovation -related aspects conditioning relevant dynamics in and around a focal regime and its associated niches.

A number of distinct concepts have been developed in order to understand the ways in which transformation is inhibited in socio-technical systems – and incumbency is maintained in regimes (48). These include 'autonomy' (28), 'lock in' (49), 'path dependency' (50) 'entrapment' (51), and 'obduracy' in 'socio-technical imaginaries' (52). More recently, notions of 'incumbent strategies' have been developed, adopting political-economic perspectives to analyse the 'resistance' of incumbents to the diffusion of alternative technologies (36,53). Similarly, recent attention has turned towards understanding how such path dependent configurations can be 'destabilised' (43) and well-established socio-technical systems become subject to active discontinuation (54,55).

Discontinuation involves overcoming both relatively emergent 'path-dependency' and more agency-driven 'entrenchment' at the regime level (56–58)(48). As Geels et al (58: 552) illustrate, incumbency-reinforcing 'lock-in' mechanisms include various forms of 'increasing return', 'learning by doing', 'scale economics', 'favourable regulations', 'sunk investments' and 'vested interests'. Likewise, contrastingly-classified similar aspects can contribute to the 'lock-out' of alternative technologies (60). From an economic perspective it follows that the greater the levels of: industrial strength; sunk capital; research and development expenditure; alignment in policy networks; and economic efficiency in the focal sector; the greater the tendencies towards path-dependency and entrenchment (ibid).

It is these factors that form core drivers in relation to the five broad criteria referred to here as being 'internal' to the 'focal regime/niche configuration' around nuclear power itself and the renewable technologies that are most challenging to this in UK and German low carbon energy strategies. Indeed, it is these factors that are seen as being especially relevant to nuclear politics, where processes of path-dependency and entrenchment are recognised to be intensified by engineering, scientific and regulatory consequences of the complexity, capital intensity and lasting nature of these projects (49,51,61). Although the technical, operational, social and environmental characteristics of different renewable technologies are highly disparate, they may nonetheless be meaningfully compared with nuclear power in these terms. And it is the priority attached to declared low carbon aims both in the UK and Germany that justifies the exclusion of fossil fuel alternatives in this analysis, as well as making it essential equally to extend analysis in principle to all potentially relevant renewable technologies, rather than simply picking the most obviously prominent.

By contrast with these factors, relevant literatures suggest a different set of issues as relatively 'external' to the focal regime/niche configuration as defined here. These broader institutional conditions do not relate only to the immediate contexts of the focal regime, its challenger niches and most directly-linked features of broader landscapes. They also pervade the entire social, cultural and political milieu in the respective national settings

(48). Here, attention expands from the relatively tight positive focus of evolutionary economics underlying transition research, to the broader interpretive scope of science and technology studies. For instance, STS analysis of ‘socio-technical imaginaries’ (52,62) and ‘civic epistemologies’ (63) illuminates potentially formative processes on a wider canvas encompassing entire polities of individual countries like the UK or Germany. Considerations include general relationships between styles of scientific knowledge production and representation and distinctive constituting dynamics around the state (64). Attention addresses how recurrent patterns in policy-making and technological cultures can reflect more messily complex and politically, culturally and discursively distributed relations and processes, that defy the neatly discrete and singular visions of ‘alignment’ underlying conventional notions of particular ‘regimes’ (48).

Perhaps most crucially, these wider and deeper issues address the general character of the institutions, practices and discourses that are variously held to constitute different instantiations of ‘democracy’. Some emerging studies in regime theory are beginning to address related contextual geographical factors (65,66), policy paradigms (67), historical institutionalism (68), state politics (69,70), and the role of political struggle (71–74). But these pervasive characteristics of political systems taken as a whole have hitherto received relatively limited attention in study of sustainability transitions (75–77). Especially neglected in this compartmentalised analysis, are the implications at the most general level of variously-definable ‘qualities of democracy’ taken as a whole (78). It is these aspects that are collectively addressed in the ‘external’ criteria (7-9) examined here.

To include holistic consideration of general qualities of democracy may be relatively novel for transition studies, but it chimes with longstanding literatures specifically on the politics of nuclear power. In recent years, research on nuclear issues has tended to become more circumscribed around a narrow policy focus on climate change, energy security and economics (79,80). The correspondingly relatively limited role for social science leaves a tendency to neglect wider issues around the democratic implications of nuclear development, that once formed a key focus of interest in nuclear politics (28,31,33,81–86). So the present analysis attends to these literatures as well as more contemporary contributions pertinent to nuclear implications beyond climate change, energy security, and economics. Indeed, it is these broader technical, economic, political and cultural aspects that are highlighted in the present criteria.

For example, Verbruggen et al (87) assess what they refer to as the ‘actual’ sustainability of nuclear power using a set of 19 criteria extending beyond the usual preoccupation with carbon alone. Based around four categories (including environmental/ecological, economics, social, and governance/policy), these include concerns such as the wider economic framework required by nuclear power to survive in current liberalised energy markets (88,89). Similar broad criteria are suggested in Hultman’s (90) focus on the social, political and economic aspects influencing nuclear development, as well as the importance of military-related activities to nuclear infrastructures. These interdependencies between civil nuclear and military-related nuclear activities were also previously a key focus (91–93), but remain largely unaddressed in contemporary research concerning the ‘nuclear renaissance’. Indeed, military industrial dynamics are virtually never considered in the normally exclusive energy policy focus of sociotechnical transitions studies of ‘nuclear regimes’. Again, it is a distinctive feature of this analysis, that this military aspect is specifically included as an ‘external’ criterion.

Since initial publication of the present research (94), some broader comparative analyses have emerged under a sociotechnical perspective of the nuclear role in energy transitions (95,96). In comparing German and Japanese electricity systems, for instance, Cherp et al very usefully highlight the importance of the relative strengths of nuclear and renewable industries and resource endowments. Crucially, Cherp et al highlight that *“the strength of the regime affects its ability to shape state policies in its own favour*” (95, p. 623). In our criteria 3 and 4, we also look closely at the relative favourability of industrial and resource conditions in Germany and the UK. In the present analysis, however, these important aspects are decomposed into a number of separable parameters, and distinctively added to consideration of a wider range of potentially key further specificities in the two countries, including military cultures and qualities of democracy.

Also following the present author's focus on multiple comparative criteria for examining nuclear and renewable dynamics in Germany and the UK [1], another article by Geels et al uses this same cross-national comparison to extend a 'multi-level' form of sociotechnical regime theory (96). Unlike the detailed analysis undertaken here and by Cherp et al (95), however, the comparative strength of national nuclear and renewable industries and resource potentials are not discussed by Geels et al. Suggestions are made for further complex additions to the favoured framework. But rather than systematically testing the applicability of the resulting new version, Geels et al focus primarily on fitting this to an interpretive account of various processes as these are described to unfold in the two countries over time. Specific parameters are not distinguished and examined for their relative consistency or tension with prior theoretical predictions. No attention is given, to whether or to what extent contrasting pictures might be suggested by considerations that are relatively 'internal' and 'external' to the prescribed approach. By simply asserting a new and more elaborate form of the same framework, an impression is given of potentially all-encompassing unfalsifiability (48).

Assembled from a mix of literatures related to socio-technical regimes as well as nuclear specific studies, the present array of economic, technical, political, and social criteria, by contrast, enables a systematic test of the validity of prior theory. Each criterion developed here addresses considerations raised in at least some particular analyses of nuclear power of a kind that might reasonably be expected, in principle, to be recognised to hold at least some significance under some conditions, bearing on prospects for nuclear discontinuation and substitution by alternative energy strategies. Despite scope for ambiguity, divergent interpretations and disagreement the array of criteria taken as a whole arguably constitutes a reasonable set of considerations that might be recognised under any interdisciplinary perspective, to offer the most significant prior explanatory value towards understanding the comparative fortunes of nuclear power in different settings.

We developed these criteria through a saturation process, attempting broadly to reflect the wide literatures mentioned above. The breath of these criteria limits depth in certain respects – for instance relating to: historical narratives, social movement complexities, discursive struggles, and ways in which qualities of democracy change over time. Elsewhere we have outlined in more detail factors such as the evolution of policy developments related to renewable developments in Germany and the UK (98 P.44) and discussions of detailed evolution of German and UK nuclear and renewable policies have been covered elsewhere (97–100). In this paper, we focus on data that illuminate broad signals under each criterion. Associated parameters do not yield in-depth narrative explanations but are extensive and clear enough for workable *ceteris parabus* propositions.

The table below outlines each criterion, identifying in each case: whether it is 'internal' or 'external'; its motivating rationale; and a selection of key relevant sources.

Table 1: Criteria, associated parameters and selection rationale.

[1] Then close colleagues in SPRU and the Sussex-led nuclear strand of the DiscGo project, Geels and Kern took part in a number of conversations and seminars on the current analysis by the present authors, in the lead up to its initial publication in 2015 (94). But they do not acknowledge their familiarity with this work by citing it (96).

Type of Criteria	Criteria number	Parameter	Rationale for selection of criterion	Selection of relevant sources drawn upon
Internal to focal regime configuration	1:0 General energy market conditions	1:1: market coordination 1.2: Relative scale of the public sector 1.3: Grid characteristics 1.4: Economic structure and energy use	Market conditions and degree of state intervention in markets are important dimensions of nuclear regimes given historic dependence of nuclear regimes on strong state subsidy and coordination and important internal factors to conventional analysis of technological trajectories such as R&D spend.	(79,84,85)
	2:0 Degree of penetration of nuclear in the electricity generating mix	2.1: Overall magnitude of the nuclear generating industry 2.2: Relative dependency on nuclear power	The larger the share of generation capacity a particular technology has, the more influence on the whole electricity system, with various sunk investments, and path-dependency related to influence on factors including grid designs, engineering expertise and associated lock-ins.	(86–88)
	3.0: the relative strengths of the nuclear engineering sector in terms of performance in manufacturing and operational equipment supply and associated industrial lobbies	3.1: Performance of plants 3.2: Comparison of constitution of respective nuclear industries in Germany and the UK 3.3: Research and Development in nuclear power 3.4 Share of global nuclear Patents (national aggregate and by company)	Increasing returns and potential lock ins are more likely with higher performing and more profitable industries than ones that are poorer-performing and more costly suggesting abandonment of technology more challenging in the former context	(85,86,89)
	4.0: Availability of national renewable energy resources	4.1 Overall renewable Resource	The ability of discontinuing from one technology to another is partly based on the energy resource available in a country and the relative costs of exploiting that resource. Countries with a more abundant resource that can be exploited for less cost can be considered more likely to move towards that option and depart from other energy pathways. This builds on literature on cost-resource curves.	(90–92)
	5.0: The scale of national industrial capacities and interests in harnessing renewable energy supply	5.1: Growth of renewables in Germany and the UK 5.2: Research and development 5.3: Industrial strength – equipment supply industries	'challenger' technologies in a 'focal regime configuration' are identified as those disruptive to the regime in question. In this case, it is renewables which pose the greatest challenge to the engineering capabilities and business models surrounding centralised nuclear power and fossil fuel technologies. If the 'challenger' or 'niche' technology is industrially stronger and better established then departing from a dominant regime may be considered more likely.	(28,93–96)
External to focal regime configuration	6.0 relative scales of military-related nuclear activities and interests	6.1 nuclear weapons capabilities 6.2 Wider military nuclear infrastructures	There is extensive literature that notes similarities in aspects of production, supply chains, and historical intertwinement of civilian and nuclear industries. The implementation of policies that separate these two nuclear sectors make any conclusion regarding the influence of military-related nuclear activity difficult. However associations in the literature would suggest a lower likelihood for a country with extensive military-related nuclear activities to discontinue from civil nuclear power. However, the authors of this paper do not make a firm conclusion one way or another but merely recognise these associations in the literature.	(81,82,97–101)
	7.0: Public attitudes and social movement activity	7.1: General public opinion on nuclear power 7.2 public confidence in the nuclear industry 7.3 public perceptions of nuclear risk 7.4 scale of social movement action 7.5 intensity of public debate including media mentions 7.6 Prominence of evidence concerning renewable pathways	Recently, sustainability transitions has begun to focus more on the crucial role that social movements and different forms of 'the public' play in the directionality of transitions pathways. Social activism and public opinion are considered especially important forces in influencing the direction of nuclear policies.	(106–109)
	8.0: General national political institutions and elite cultures	7.1 centralisation / decentralised political system 7.2: Prominence of Green Party	Contextual factors such as political cultures are recognised 'external' factors to a focal regime configuration. Recently, transitions theory has begun to pay more attention to these broader political factors that contribute to the directionality of transitions. With nuclear, decentralised and consensus systems are often cited as being important in allowing critical opponents of nuclear to influence policy.	(13,36,59,102–105)
	9.0 Qualities of national democracies	9.1 Tendency to deliberative-style politics 9.2 Majoritarian Vs consensual 9.3 democracy Barometer analysis 9.4 Economist intelligence Unit analysis 9.5 Global Democracy ranking analysis	Literature comparatively assessing democracies is drawn upon to clearly ascertain differences between Germany and the UK with respect to 'democratic qualities'. This is combined with literature that highlights issues of secrecy, lack of transparency and insufficient public engagement in the development of nuclear power in certain contexts, where the relationship between nuclear power and democracy have previously been a central point of discussion	(69,73,110,111)

3: Empirical Discussion of Case Studies

This section outlines empirical findings obtained under the framework detailed above. For each criterion, a number of specific parameters are discussed that might reasonably be held to bear on the likelihood of nuclear discontinuation. Based on this, each criterion ends with a '*ceteris paribus* proposition' concerning whether – with all else being notionally equal – nuclear discontinuation might in these terms reasonably be judged to be more or less likely in Germany or in the UK (or to be indeterminate). The evidence for this discussion is drawn from the literatures considered above on socio-technical change as well as in nuclear specific literatures as detailed in Table 1.

3.1 General Energy Market Conditions

3.1.1 Market coordination

Germany is a paradigmatic example of a *'coordinated economy'* with relatively strong state intervention in policy (101–104). The UK, by contrast, is a 'liberal-market economy' displaying generally less state intervention and coordination (105–107). Accordingly, the UK privatised the energy industry eight years before Germany (108) and broadly followed a more "pro-market energy paradigm" since 1989 (109). Rapid UK electricity privatisation caused considerable problems for nuclear, not least the 2002 bankruptcy of British Energy (110). Also crucial to this parameter is the clear documentation of closer alignment and planning between publically-owned financial institutions and industry in Germany (111–113). Given well-documented problems around financing of nuclear projects (114–116) and the long time-horizons and high levels of historically-necessary public investment (117–121), Germany's general market and financing culture are thus clearly more suited to this technology than the liberalised market-based approach of the UK.

Of course, questions might also arise as to whether a greater degree of market coordination might also be an advantage for renewable energy (96). Whilst dependent on government policy initiatives, however, it is significant that German renewable developments have been significantly more diverse and less dependent on state institutions and their major corporate partners than is nuclear power (35,122). Also given the greater proportional scale of the nuclear industry in Germany (section 3.2), the main expectation under this parameter would therefore most reasonably remain that stronger levels of market coordination in Germany would (all else being equal and on balance) tend more likely to favour nuclear power (123).

3.1.2 Relative scale of public sector

In 2011, public expenditure accounted for 44% of German GDP, in 2000 this figure was 47% (124). In the UK, public expenditure accounted for 39% of GDP in 2010 and 37% in 2000 (ibid). This might be considered an internal parameter because the scale of public spending provides a useful signal regarding political economic characteristics of the German energy sector – it is recognised that state investment has since the 1980s generally played a more important role in the German than the UK energy sector (105). Indeed, the German economy being more weighted than the UK towards the public sector has been observed to hold important ramifications for the respective strengths of the German and UK nuclear industries (110,125). As the IEA point out, *"…access to direct or indirect government financing also continues to be an important factor for nuclear investments"* (124, p.154).

3.1.3 Grid Characteristics

Both Germany and the UK traditionally relied on centralised electricity grids dominated by large power stations (96) so there seems no obvious infrastructure rationale why the phasing out of nuclear and deployment of renewables would better suit the historic circumstances of the German than the UK grid. However, another relevant factor here might concern interconnection. That the continental location of the German grid makes it more internationally interconnected than the island-based grid of Great Britain, might make the management of intermittency easier (126). If so, this would only become an issue at higher penetrations than are relevant for our period, thus impinging more on planning, than on operations. Either way, with European electricity exports dominated by the nuclear system of France, greater interconnectivity might just as readily be seen as an advantage for the German nuclear industry. Added to this, greater infrastructure and contractual connections might also on balance be held to make it more difficult for one party to make a distinctive move not also followed by its partners, as has been the case with the German Energiewende. In the case of the UK, on the other hand, concerns around the relative dearth of interconnection may indeed have contributed towards calls for new generation capacity. But with renewable capacity available at lower cost, it is not clear why this should automatically favour nuclear capacity. With interconnections set to double by the early 2020s with no noticeable attenuating effect on nuclear ambitions, the difference in this respect between the two countries is diminishing (127).

3.1.4 Economic structure and energy use

It is also important to consider energy users in the wider economy in Germany and the UK and how they may impinge on nuclear trajectories. According to World Bank data, the manufacturing share of GDP is 21% in Germany and only 9% in the UK (128). This pattern is especially pronounced in respect of some of the most energy-intense sectors – with the German steel, chemicals and automotive industries especially more developed than those of the UK (107). It is notable that it is energy intensive industrial interests that have often most strongly lobbied for 'firm' power sources including nuclear (129) and raised greatest concerns over the effects of renewables on electricity prices (129,130).

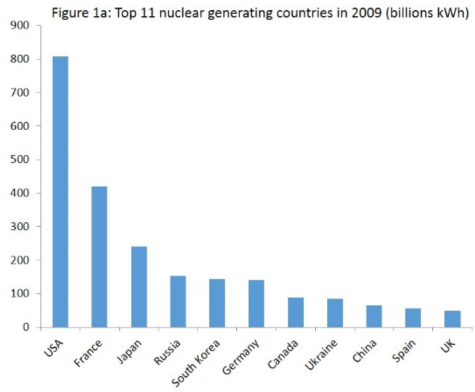
3.1.5 Ceteris paribus proposition

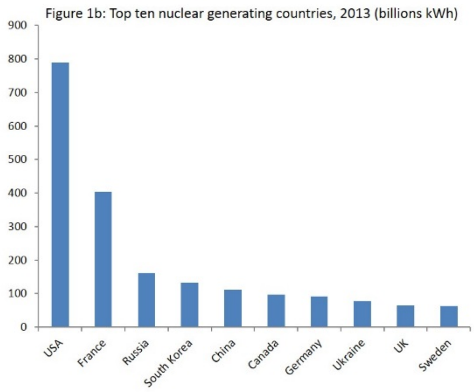
Given that the large scale and high capital intensity of nuclear power demand strong state involvement, higher German levels of public spending and state intervention in markets seem in principle to be more favourable to nuclear continuation in this country than in the UK. That German industry is more energy intense compounds this. There is little about grid interconnectdeness that would reverse this picture. So – all else being equal – a criterion of energy market conditions might most reasonably be thought to make nuclear discontinuation less likely in Germany than the UK.

3.2: Degree of penetration of nuclear in the electricity generating mix

3.2.1: Overall magnitude of the nuclear generating industry

Figure 1a (below) shows that in 2009 before Fukushima, Germany generated more than twice the absolute amount of electricity from nuclear power than was produced in the UK (Fig. 1a). Figure 1b shows a similar situation persisted after Fukushima in 2013, with Germany still producing significantly more nuclear electricity than the UK, ranking seventh in the world for total nuclear generation, compared with the UK at ninth. This is despite the stronger negative reaction to this nuclear accident in Germany compared with the UK, with 8 reactors having been closed immediately after Fukushima. Table 2 shows the same picture to have prevailed historically and that the average size of individual German reactors is also significantly larger.





Source: IAEA (131), Nuclear Energy Institute (134)

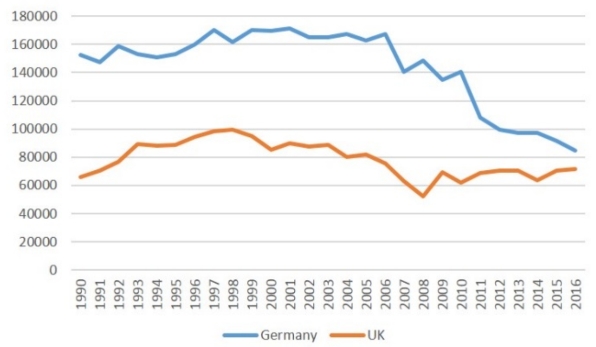
Table 2: Scale of German and UK nuclear power industries

	GERMANY	UK
Production of nuclear energy in 2010 (GWh)	140556	62120
Average reactor size in 2010 (MWe)	1196	548
Average annual production 1990-2016 (GWh)	144,020	78,461
Historic maximum nuclear production in one year (GWh)	171,305 (in 2001)	99,486 (in 1998)

Source: IEA (132) World Nuclear Association (133)

Figure 2 (below) provides further historical context, showing that the German industry was persistently significantly larger than that of the UK over the period prior to the 2011 post-Fukushima intensification of the Energiewende – and indeed even afterwards.

Figure 2: German and UK Production of nuclear power (GWh) 1990-2016



Source: IEA (132)

3.2.2: Relative dependency on nuclear power

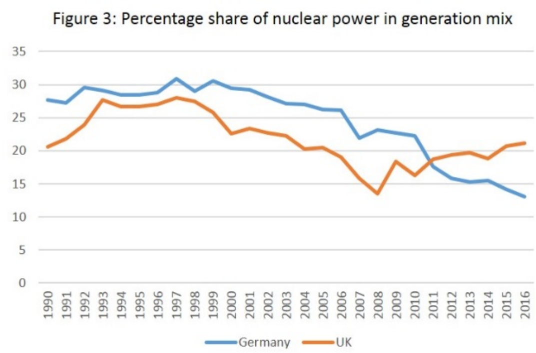
A measurement enabling easier comparison between nuclear dependencies in Germany and the UK is the relative importance of nuclear in the supply mix. Table 3 and Figure 3 (below) confirm that throughout most of the period considered here, the larger German electricity system has consistently been more dependent on nuclear power than has that of the UK.

Table 3: Indicators of nuclear penetration in the UK and Germany

	GERMANY	UK
% share of electricity generation in overall mix (2010)	22%	16%
Maximum historic share of nuclear in generation mix (%)	30.8 (1997)	27.9 (1997)
Average share of nuclear in generation mix 1990-2016 (%)	25	22

Source: IEA (132) World Nuclear Association (133)

Figure 3: Percentage share of nuclear power in generation mix



Source: IEA (132)

3.2.3: Ceteris paribus proposition

It is clear both in relative and absolute scale, that the German nuclear industry has long been significantly larger than that of the UK. To the extent that this simple magnitude might be held to relate to a greater degree of 'lock-in', it might reasonably be inferred – all else being equal – that Germany would face greater challenges than the UK in seeking to phase nuclear out.

3.3: The relative strengths of the nuclear engineering sector [2]

3.3.1: Performance of plants

The most important general measure of performance in the nuclear generating industry is load factor, referring to actual output as a fraction of total possible output. In these terms, the 13 highest performing nuclear power plants worldwide are sited in only 3 countries: 6 in South Korea, *5 in Germany*, and 2 in Finland (118). German reactors hold the first eight positions in *Nuclear Engineering International's* league table of the reactors that have generated the most electricity to date (135). Load factor is an important proxy for manufacturing and equipment quality, because it is dependent to a large extent on system engineering. So it is relevant in this regard, that, the top three lifetime electricity generators (TWh) at the end of 2011 were all in Germany – Grafenrheinfeld, Grohnde, and Philippsburg 2 (136). The best performing reactor in the world in terms of average lifetime load factor is Grohnde in Germany (ibid). On many other indicators including construction costs, capital costs, operating costs, and load factor, Germany is considered to host one of the best performing nuclear engineering industries in the world (137). This is in strong contrast to the UK, where it is noted by UK policy makers and key reports that the UK performs strikingly poorly overall on most international comparisons related to plant performance (125,138).

3.3.2: Comparison of constitution of respective nuclear industries in Germany and the UK

Both Germany and (with its longer nuclear history) the UK have substantial expertise supporting nuclear services such as fuel fabrication and enrichment as well as 'backend' activities like decommissioning and the managing of nuclear wastes. However the most salient factor with regard to industrial commitments to new build (rather than clean-up) relates to the comparative strengths of the national nuclear engineering sector. Table 4 provides information on the relative standing of key engineering companies, the international profile of nuclear operators and their respective commercial scale and employment contributions.

[2] The highly distinct nature of the technologies involved means that this analysis of the nuclear engineering sector is limited to nuclear fission, rather than also including nuclear fusion. R&D data gathered from IEA is based on category 41 labelled 'nuclear fission', which excludes R&D related to nuclear fusion activities. The 'nuclear fission' category includes R&D related to the disposal of nuclear waste resulting from nuclear power production.

Table 4: relative strengths of Germany and British nuclear industries

	Germany	UK
Reactor Vendor companies	Siemens one of the most successful reactor vendors in the world with decades-long reactor sales experience (including to Brazil, Iran, Argentina and Eastern European states) until abandoning nuclear operations in 2012	No nuclear reactor vending since the early 1960s when UKAEA sold a total of 2 reactors to Japan and Italy.
Companies involved in operation, ownership and sale of nuclear electricity	RWE, E.ON, EnBW are all international nuclear operators headquartered in Germany	There is no UK headquartered company that is a major nuclear power utility company
Estimated nuclear labour force in civilian nuclear power in 2010 (directly employed by nuclear companies)	38,000 (civilian nuclear power excluding waste disposal)	30,000 (excluding waste disposal such as Sellafield that employs 10,000 people)

Sources: (138–141)

3.3.3: Research and development in nuclear power

The relative scale of research and development efforts in nuclear fission also provide an interesting basis for comparison between the UK and Germany. The graphs below charts historic UK and German expenditure on nuclear R&D. Germany has consistently spent more money on nuclear-related R&D than the UK (fig. 4a) and Fig.4b shows the nuclear proportion of total civilian energy R&D spend in each country:

Figure 4a: UK and German civilian nuclear R&D expenditure in million Euro (2017 prices & exch.rates), 1974-2013

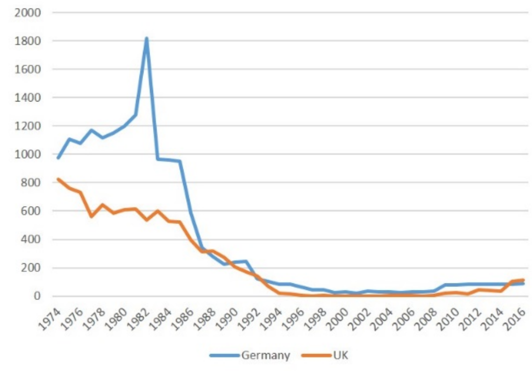
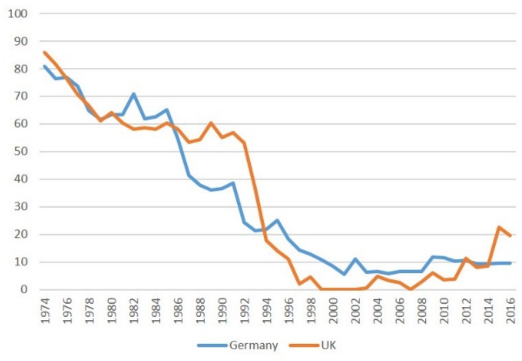


Figure 4b: nuclear R&D spend as a percentage of overall energy R&D spend (%)



Source: IEA (142)

3.3.4 Share of global nuclear patents (national aggregate and by company)

Another indicator of the relative strength of nuclear engineering activity, is the volume of patenting for nuclear fission technologies. Whilst there are many pitfalls in seeking to use patent data as indicators (143) and conclusions regarding the strength of nuclear industry cannot be made on this parameter alone, a relevant ‘innovation index’ nevertheless shows striking results providing a salient signal regarding the relative success of German and UK nuclear industries depicted in figures 5a,b and c below.

Figure 5a: German and French nuclear innovation index

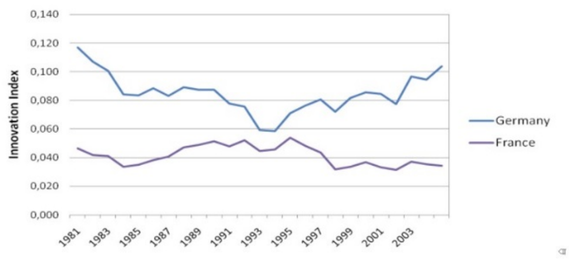


Figure 5b: Share of worldwide nuclear patents by country

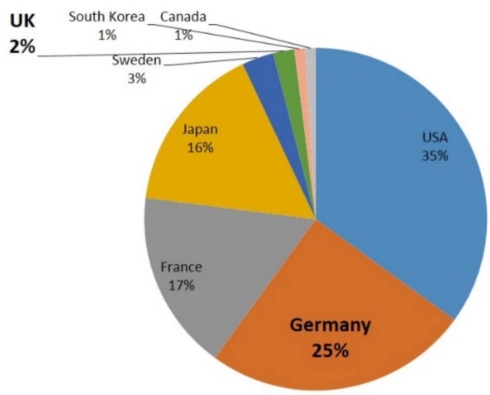
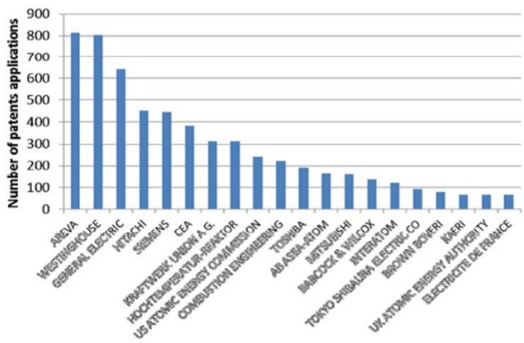


Figure 5c: patent applications for civilian nuclear power by country



Sources: Lévêque (144), Berthélemy (145)

Figure 5a indicates German patenting compares favourably even with that of France, as the historic global leader in nuclear construction (146). In order to resolve the far less significant position of the UK, direct patenting data can be examined. Figure 5b shows the share of total patents relating to nuclear power over the past few decades between key countries. Germany has the second largest share following the USA, with 25% of worldwide patents, whilst the UK has only a 2% share. The absolute numbers of patents behind this picture is shown in Figure 5c for the period 1974-2008, with Germany again significantly outperforming the UK.

If patterns at the firm level are felt more relevant, it is significant that three German companies (Siemens, Kraftwerk Union, and Hochtemperatur-Reactor) perform among the top ten in the world for nuclear patent applications. UK organisations feature only at the bottom of the table, with Babcock and Wilcox at 7th lowest and the Atomic Energy Authority holding the second lowest number of patent applications of those surveyed.

3.3.3: Ceteris paribus proposition

Table 5 (below) summarises the overall picture under this criterion. It is clear that Germany has a far stronger nuclear industry on nearly all counts than the UK. All else being equal, nuclear discontinuation might under this criterion be considered less likely in Germany than in the UK.

Table 5: Summary table of nuclear R&D in Germany and the UK

	Germany	UK
Total R&D spent on civilian nuclear 1974-2016	€17.1 billion	€9.8 Billion
% of total Energy R&D expenditure dedicated to civilian nuclear power, 1974-2013	45%	49.5%
Amount spent on nuclear R&D in 2010	€79.9 million	€22.4 million
% of overall expenditure of Energy related R&D in 2010	11.5%	3.4%
Approximate number of patent applications 1974-2008	1050	250
% total of civilian nuclear patent applications 1974-2008	25%	2%

Source: compilation of previous sources above.

3.4.: Availability of national renewable energy resources

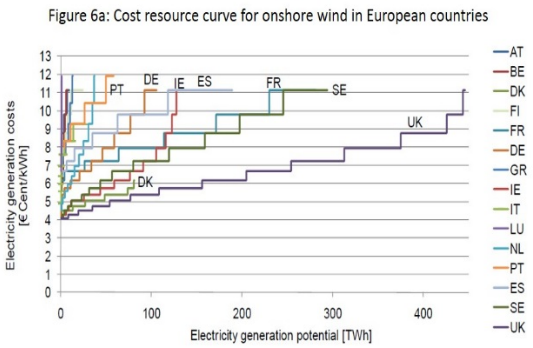
3.4.1 Overall renewable resource

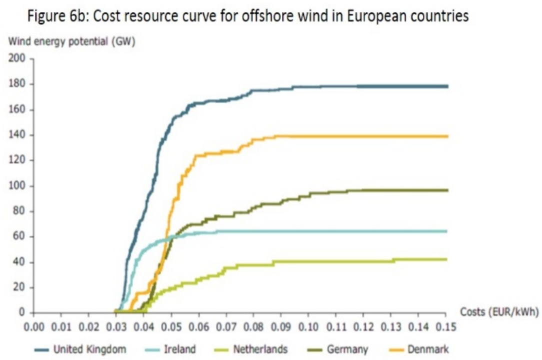
A further important consideration when thinking about the substituting of nuclear power by alternative low carbon strategies, is the potential magnitude of national renewable energy resources and the costs and operational ease with which these can be harnessed (this is a separate matter to the realised scale of national renewable industries, which forms a distinct criterion later). In these terms, the renewable resource base is best understood as the energy that might potentially be utilised under standardised assumptions concerning resource availability and economic costs of exploitation. This involves both theoretical and technical considerations that are well explored in various intensive studies conducted across different European countries on a comparable basis (147). The overall position as between Germany and the UK is quite unambiguous.

In the case of hydroelectricity, most feasible sites in the UK are considered to be already utilised (150), with the technical challenge lying simply (and more marginally) in plant improvement. With other technologies, however, the picture is different. However, the UK has 40% of the total economic wind energy resource in EuropeIt is repeatedly and without controversy assessed to enjoy the best wind resources on the continent (151–154). As the 'windiest place in Europe' (155), the UK has vast potentials for viable offshore wind power. Scotland alone has 25% of the total European offshore wind resource (148). The picture is similar for wave and tidal power, where the UK alone is assessed to hold 50% of the total economic European potential (156). The Severn estuary alone presents one of the most attractive sites in the world for development of large scale tidal power (149).

Wind

A more detailed picture can be resolved in 'cost-resource curves' for the most important renewable resources. A systematic analysis of this kind for onshore wind power by Held (157) in Figure 5a and by the European Environment Agency in figure 5b, shows the costs at which successively larger volumes of energy production can be realised from this source in different European countries. The UK is by far the most well-endowed country in Europe both in terms of onshore and offshore wind, with Germany performing relatively poorly.





Sources: Held (157), European Environment Agency (158)

Solar

Solar is arguably the second most important renewable resource. Here, the demanding nature of this kind of analysis, means that cost curves for solar are harder to come by. However the *Green-X study* in 2003 does give a quite comprehensive indication across Europe for 2020, of both potential capacities and their associated cost profiles in €/ MWh. As detailed in Resch et al (159) some parts of the UK have comparable solar resources to Germany, yet have not exploited this resource. With resource magnitudes partly driven by the larger area of Germany when compared to the UK, discrepancies between resource potential and relative costs are small. Table 6 below, details the key differences:

Table 6: Comparative solar resource and costs for Germany and the UK

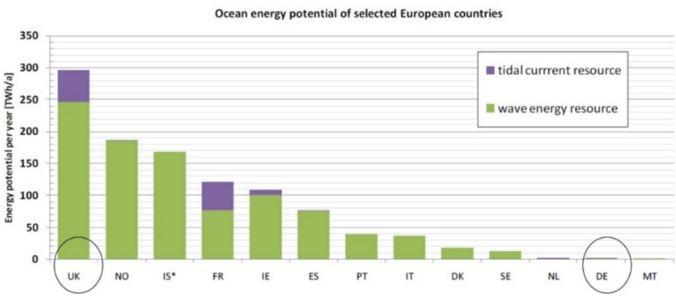
	Germany	UK
Mid term energy potential (GWh)	52393	43040
Capacity potential (MW)	71929	64844
Average full load hours	728	664
Cost of electricity (min) (€/MWh)	716,0	787,6
Cost of electricity (max) (€/MWh)	1423,0	1565,3
Cost of electricity (average) (€/ MWh)	970,0	1063,1

Source: Resch et al (159)

Marine Energy

Looking further into the future, other important renewable resources include marine energy from wave and tidal power. Whilst costs are more difficult to ascertain confidently for these options, they will be comparable between the two countries. It is clear again that the large coastline of the UK leads it to enjoy far more favourable endowments of marine energy than Germany (fig.7):

Figure 7: Wave and tidal potential resource



Source: Fraunhofer-ECORYS (160)

Biomass

Biomass is also an important potential renewable energy source in both the UK and Germany. Here precision in cost-resource estimates are complicated by greater contextual variability – for instance in production of agricultural residues and other diverse forms of potential biomass resource. The table below (table 7) however, summarises key recent estimates of the mid-term potential and costs of biomass in both Germany and the UK. Depending on assumptions, it should be noted that the position of Germany might be generally more favourable than suggested in this table, due to the relatively greater access to important sources in Scandinavia. However, if landfill gas is considered to be a form of biomass (often the case in the UK, where it is arguably among the most attractive of such resources), the long-standing adoption of recycling and incineration as waste management strategies in Germany has the opposite implication for the relative scale of the biomass resource.

Table 7: Overview of additional realisable potential and costs of Biomass in Germany and the UK

Biomass Product	Germany	UK
Biomass – forestry products		
Electricity gen. potential GWh	14560	1834
Short run marginal costs (€/MWh)	62.3	65.9
Long-run marginal costs (€/MWh)	100.6	104.2
Biomass Forestry products, Combined heat and power (CHP)		
Electricity gen. potential GWh	12675	1596
Long-run marginal costs (€/MWh)	69.4	73.1
Short run marginal costs (€/MWh)	38.3	42.4
Biomass Forestry Residues (pure power generation)		
Electricity gen. potential GWh	6271	3440
Long-run marginal costs (€/MWh)	58.0	71.0
Short run marginal costs (€/MWh)	33.5	33.5
Biomass Forestry Residues (CHP)	6271	3440
Electricity gen. potential GWh	5459	2995
Long-run marginal costs (€/MWh)	84.4	84.4
Short run marginal costs (€/MWh)	-4.2	-4.2
Biomass – agricultural products (PPG)		
Electricity gen. potential GWh	22966	12893
Long-run marginal costs (€/MWh)	118.6	123.6
Short run marginal costs (€/MWh)	80.3	85.3
Biomass – agricultural residues (PPG)		
Electricity gen. potential GWh	12926	6848
Long-run marginal costs (€/MWh)	97.1	100.6
Short run marginal costs (€/MWh)	58.7	62.3
Biomass Agricultural Residues (CHP)		
Electricity gen. potential GWh	11252	5962
Long-run marginal costs (€/MWh)	113.3	117.5
Short run marginal costs (€/MWh)	24.7	28.8
Biomass – biodegradable fraction of waste (PPG)		
Electricity gen. potential GWh	4677	3442
Long-run marginal costs (€/MWh)	84.4	84.4
Short run marginal costs (€/MWh)	-0.3	-0.3
Biomass – biodegradable fraction of waste (CHP)		
Long-run marginal costs (€/MWh)	29.5	29.5
Short run marginal costs (€/MWh)	58.6	58.6

Source: Fhg-isi, Huber, & Eeg, (161)

3.4.6 Ceteris paribus proposition

On this basis, it is possible despite the diversities, complexities and ambiguities to conclude both in terms of the scale of the overall resource and the costs at which different tranches are available, that the UK unequivocally enjoys a superior overall national renewable energy endowment to Germany. This applies especially to the most important on- and offshore wind resources, as well as to wave and tidal and many other particular forms of renewable energy, on which it is harder to be precise. Specifically with respect to solar power and some biomass sources, Germany appears slightly better off, but the differences are marginal when compared to the countervailing situation for other technologies. With much of the data substantiating this picture going back to the 1970s (162–164) the manifestly more favourable position of alternatives mean that nuclear discontinuation might – all else being equal – be thought to be more likely in the UK than Germany.

3.5. The scale of national industrial capacities and interests in harnessing renewable energy supply

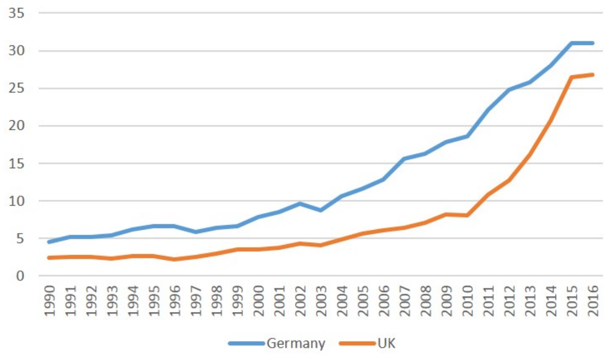
This section provides an overview of industrial capacities in Germany and the UK associated with the development of national renewable energy resources. Using IEA data, a series of tables document growth in various renewable technologies from 1990-2016 (conveying market scale), R&D expenditure into various renewables technologies (as a proxy for likely support in certain technologies), and an assessment of the comparative position of renewables industries and equipment supply industries in each country. An associated wider narrative analysis of renewable developments in these countries has also been undertaken by the authors (and is consistent with this picture), but is reported on elsewhere (98 p.44).

3.5.1: Growth of renewables in Germany and the UK

Growth in overall renewables production in Germany and the UK

Figure 8 highlights the overall growth in renewables production in German and the UK. While Germany made an earlier start in terms of policy support for renewables, in recent years the UK's share of renewables in electricity generation has rapidly accelerated.

Figure 8: % share of total renewables in electricity generation



Source: IEA (117)

Wind power

As Figures 9a and 9b (below) illustrate in both absolute and relative terms, Germany has deployed more wind capacity at an earlier stage than the UK, however in terms of the share of wind in electricity generation (fig. 9b), the UK has caught up with Germany in the last few years. This is in part a result of the UK's disproportionately attractive offshore wind resource discussed above.

Figure 9a: wind power: Wind power production (GWh)

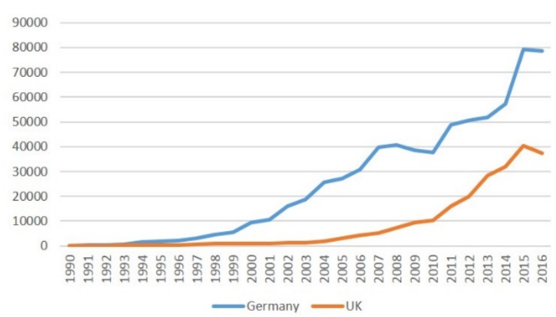
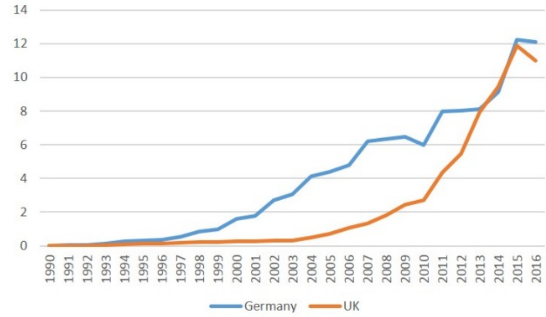


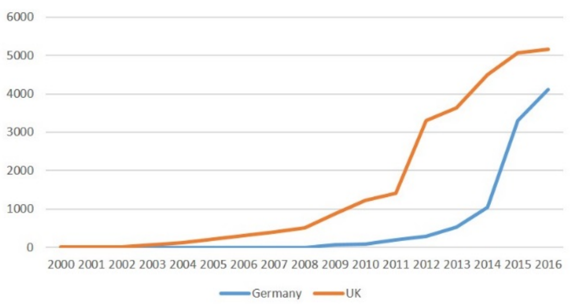
Figure 9b: % share of wind in electricity generation



Source: IEA (132)

This greater offshore wind resource, has seen the UK enabling a larger absolute deployment of offshore wind (fig.10).

Figure 10: Deployment of offshore wind capacity in Germany and the UK (MWe)

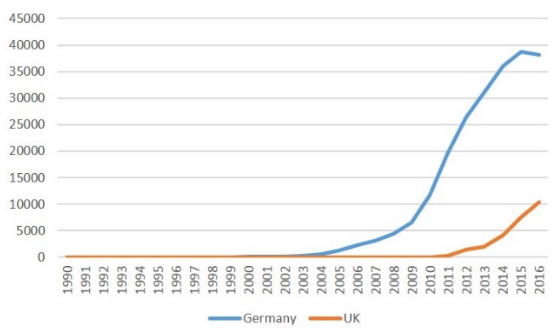


Source: EWEA, DECC, Wind Europe (165–172)

Solar power

Figure 11 shows the growth in solar capacity in both Germany and the UK. Again, Germany experienced more rapid growth in solar power, with UK growth beginning several years after Germany with the Feed in Tariff system for solar established in 2010, 10 years after Germany's Renewable Energy Act.

Figure 11: Electricity generation from solar PV (GWh)



Source: IEA (132)

Biomass

Germany and the UK have both utilised biowaste and biofuels, which have grown as a proportion of electricity production as seen from the tables below (fig 12a and 12b). In the UK increasing use of biomass was supported through the *Non-Fossil Fuels Obligation* and then the *Renewables Obligation*, with DECC later implementing Feed-In-Tariffs for small scale biomass in 2010. In Germany biomass has been stimulated by the *Electricity Act* of 1990, the Renewable Energy Act 2000, and the National Biomass Action Plan in 2009.

Figure 12a: Electricity generation from bio waste (GWh)

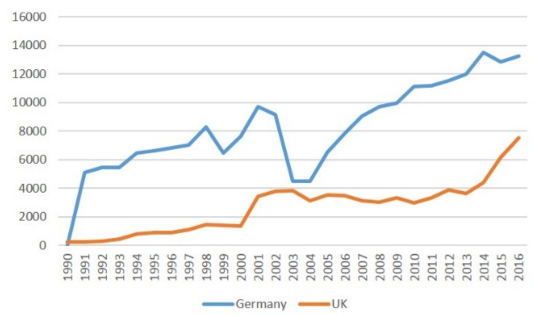
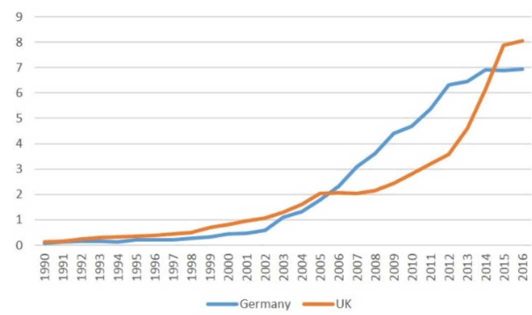


Figure 12b: Percentage of electricity provided by biofuels (%)



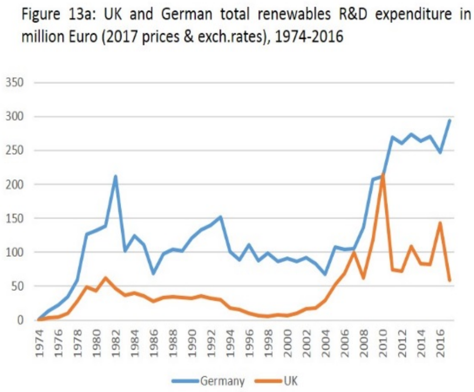
Source: IEA (132)

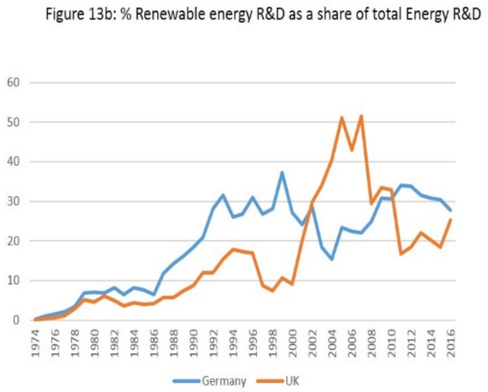
What is undoubtedly clear is that across most technological areas, Germany has generally deployed more renewable energy, beginning in most cases, at a notably earlier stage than the UK. An exception here is with offshore wind, where UK resource endowments lead it to be a world leader in terms of total installed capacity. But even here, the lead roles taken in the exploiting of this by non-UK (including German) renewable energy firms) (173,174) diminishes the salience of this contrast [3].

[3] Despite the UK's global lead in terms of amount of installed offshore wind capacity, much of the value of these projects in the UK is accrued by companies headquartered in other countries including Germany. 92.7% of offshore wind capacity is owned by companies not headquartered in the UK (284). Many offshore wind developments have only 32% UK content (285). UK companies have only a 5% share of the overall European offshore wind market (285). Only 18% of manufacturing and construction is sourced in the UK (284), with major UK supply chain gaps in turbine construction and foundation supply. Given 50% of the value of a typical offshore wind project accrues from turbine construction, considerable value is not being captured by the UK supply chain. Each additional increase of UK content by 10% per GW of installed capacity is estimated to

3.5.2: Research and development

The next parameter of interest in this area, concerns general comparative patterns in research, development and demonstration in the renewables area across the two case study settings. The figures below trace the absolute expenditure on renewable R&D[4] in the two countries (Fig. 13a) and the percentage share of R&D expenditure for renewables as a share of total R&D expenditure on energy (fig. 13b), and the table that follows (table 8) outlines key facts related to this:





Source: IEA (142)

Table 8: Total Renewables R&D spend, Percentage of renewable R&D as part of total energy R&D, 1974-2016

	Germany	UK
Total Renewables R&D 1974-2013	€6.1 Billion	€2.1 billion
% Renewables as share of total energy R&D, 1974-2013	16.1%	11%

Source: IEA (142)

The UK devoted a smaller share of energy R&D to renewable energy sources until 2002 when the UK rapidly increased its share of energy R&D spent on renewables. This declined sharply in 2008 following the financial crisis and again in 2010 following change in Government. What is most interesting from our perspective however, is that in the 1970s through the early 1980s the share of energy R&D spent on renewables by the UK and Germany were comparable before Germany began to rapidly increase its R&D spend on renewables following reorientation of spending due to policy responses to Chernobyl.

Figures 14a, b and c below show R&D funding for different types of renewable energy. Activity in both Germany and the UK was sparked initially by the Oil Crisis of 1974. The countries both took different approaches as documented by the following figures:

accrue an additional net £500m-£600m for the UK economy so significant revenue is currently flowing out of the UK based on current content levels.

[4] This relates to overall renewable energy rather than just renewable electricity production, however, as with nuclear power, the main application of renewable energy sources is the production of electricity.

Figure 14a: Ocean Energy R&D, UK and Germany in million Euro (2017 prices & exch.rates)

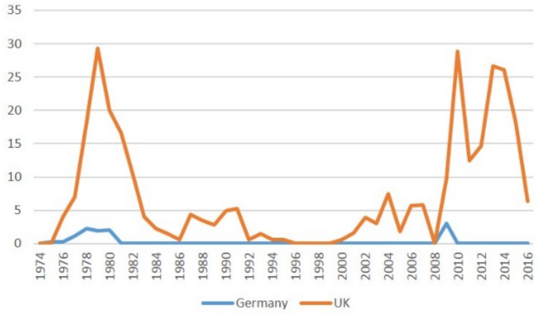


Figure 14b: R&D expenditure on solar energy 1974-2016 in million Euro (2017 prices & exch.rates)

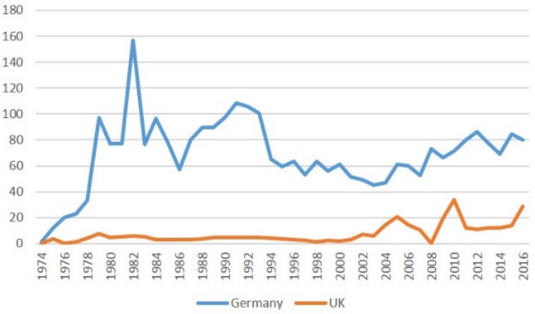
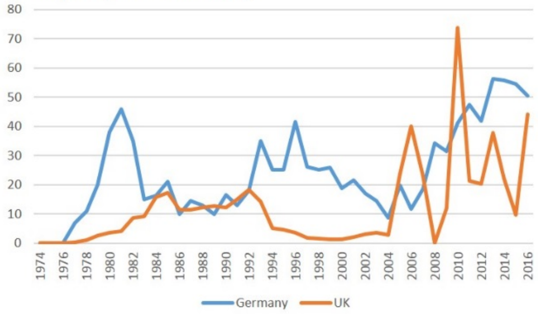


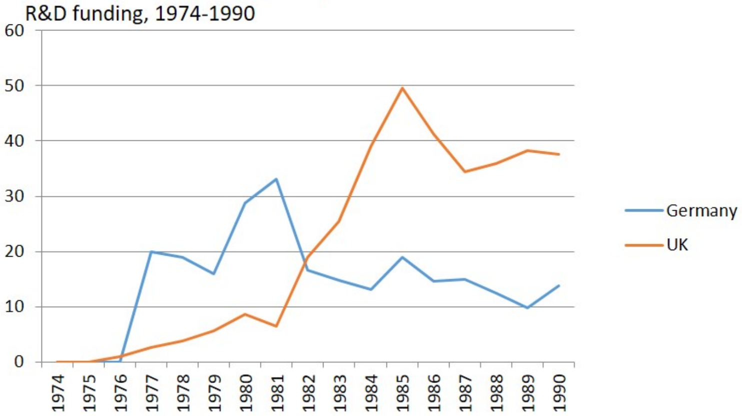
Figure 14c: R&D expenditure on wind energy 1974-2016 in million Euro (2017 prices & exch.rates)



Source: IEA (142)

During the 1970s in the UK there was substantial public investment in ocean energy whilst Germany was negligible. Germany has spent consistently more on solar R&D than the UK since the early 1970s. Germany began to invest substantially in wind energy R&D in 1977, with a notable peak of spending the equivalent of €40 million in 1981, before a rapid decrease in spending. It should be noted that throughout the 1980s, the UK was spending on par, or in some years, spending more than Germany throughout the period from 1982-1992 a crucial formative period preceding the ‘take off’ of the *Energiewende.* In terms of R&D spend on wind energy as a percentage of total renewables R&D funding the UK was devoting a greater share of its R&D resource to wind energy through the 1980s before R&D spend on energy was considerably reduced in the 1990s (fig. 15):

Figure 15: % wind energy R&D spend as share of overall renewable R&D funding, 1974-1990



Source: IEA (127)

Thus, Throughout the 1980s the UK was spending at similar levels to Germany (fig.14c) and devoting a greater share of its renewables budget to wind power (fig. 15). This was despite Germany's initial steep and short lived increase in renewables spending at the end of the 70s.

3.5.3: Industrial strength – equipment supply industries

The tables below aim to give a general overview of differing aspects of the equipment supply industries of Germany and the UK with respect to renewable energy. Once more, it must be added that given space constraints this is by no means exhaustive, however aims to outline the general patterns.

Table 9: overview of renewables capacity

	Germany	UK
Gross electricity generation from renewables (2010, GWh)	117573	30740
2010 renewables production figures (%) total electricity production)	18.6%	8%
Gross electricity generation from renewables (2016, GWh)	201086	90991
2016 renewables production figures (%) total electricity production)	31%	27%
Number of people employed in renewable industry	371,000	103,000

Sources: (132,175–177)

Table 10: Wind Energy Industry

	Germany	UK
Main Turbine parts Manufacturers	Enercon, Nordex, REPower, Vensys, Siemens	At present, there are no British companies manufacturing main turbine parts.
Component Parts Manufacturers	Eckerle Hydraulic Division, SCHAAF GmbH & Co KG, Friedrich Wilhelms-Hütte Eisenguss, Haw Hydraulik SE	GE Power, James Walker Tension Control Systems, 'Blade Materials' produced by BGB (slip rings) and Cooper and Turner (large slip rings), and Gear boxes produced by Dave Brown Gear Systems. Also 'developmental activities' including planning and consultancy work.

Sources**:** BVG Associates, Lütkenhorst & Pegels, RenewableUK, Wind Power Monthly (130,178–180)

Table 11: offshore wind industry

	Germany	UK
Cumulative installed offshore wind capacity (MW) 2010	92	1225
cumulative installed offshore wind capacity (MW) 2016	4108	5156
Main Turbine Manufacturers	Siemens, BARD, Repower, Nordex SE, Enercon, Senvion,	There are currently no UK based Turbine manufacturers
Offshore wind development	RWE, E.ON	SSE Renewables
Utility ownership of Offshore wind	RWE, E.ON	Centrica, SSE Renewables
Foundations, Component part manufacture, developmental work.	EEW, Friedrich Wilhelms-Hütte, MeuselwitzGuss, Siempelkamp, Georgsmarienhütte, Richter Maschinenfabrik, Bosch Rexroth, Eickhoff, Liebherr,	GE Power, James Walker Tension Control Systems, 'Blade Materials' produced by BGB (slip rings) and Cooper and Turner (large slip rings), and Gear boxes produced by Dave Brown Gear Systems. Also 'developmental activities' including planning and consultancy work.

Sources: (167,168,171,174,178,180)

Table 12: Solar industry overview

	Germany	UK
Total production in 2010 (GWh)	11729	40
Total production in 2016 (GWh)	38098	10421
Industrial profile	There are 46 companies based in Germany manufacturing silicon, wafer, cell modules, 61 companies producing PV module materials, 53 producing PV system components, 94 producing PV equipment suppliers, 63 producing PV mounting tracking systems, and 73 specialist R&D institutions focussed on innovation in solar energy. World-leading companies include Bosch, Solar Energy, Schott Solar, Conergy, SolarWorld, Sovello. It must be noted that the German PV Industry is facing significant problems with many companies going out of business due to cheap solar production in China rendering much German manufacturing uncompetitive, as well as takeovers by Chinese companies.	There are currently no UK-based manufacturers of solar modules, Substantial expertise has been built in the UK with installations and maintenance of solar panels including Solar Century, Solar Tech, Big Green Company, A Shade Greener, Solus, Emotion Energy, South Downs Solar, Space Renewable Energy LTD.
Jobs supported	20, 176	13, 867

Sources: (139,143–145)

Table 13: Biomass industry

	Germany	UK
Total production in 2010 (GWh)	40698	13673
Total production in 2016 (GWh)	58255	34849
Industry profile	Key players operating in German biomass include: RWE Power, AE E Lentjes, GmbH, BMP Biomasse Projekt GmbH, Interargem, BPRe Biopower Renewable Energy, ENRO AG, PROKON Nord Energiesysteme, GEE Energy GmbH Co KG, and EnBW Energie Baden-Wurttemberg	The UK's biomass market is largely dominated by Drax Power Limited, a UK company. Wartsila Corporation, E.ON UK, Scottish and Southern Energy, EDF Energy, Energy Power Resources (EPR), Bronzeoak Company, Pure power Holdings Limited, and Welsh Power Group Limited.

Sources: (132,176,185)

3.5.4: Ceteris paribus proposition

From the above it can be concluded on the face of it that – as of the current situation – Germany has a stronger renewables sector than the UK with greater penetration in the electricity mix and dominance in supply chains for renewable technology. The UK has however lead the way in recent years in terms of deployment of offshore wind, as measured by capacity. Yet this has growth has to a significant extent been driven by industrial leadership on the part of non-UK (including German) companies. In seeking to draw conclusions from this complex picture with regard to aspects that are relatively 'internal' or 'external' to regime theory, a crucial issue concerns time. The current relative status of renewable industries in the UK as compared with Germany might as reasonably be seen as consequences as they are drivers, of the divergent national energy trajectories. As reflected in the data reviewed above, for instance, it is difficult to understand the recent move of Siemens from being a leader in nuclear technology and a leader in renewable technology, without reference to the changed climate over the past fifteen years or so in German energy policy that it is precisely the point of this analysis to address (186).

In order to address this point fully, what would be necessary would be a more historical analysis of the relative situations in the relevant national renewable industrial bases in German and the UK at a time prior to the emergence of a significant divergence in the orientations of national energy strategies analysed here. But in going back to a period before large scale development of renewables there emerges a challenge in identifying confidently exactly which related areas of engineering, manufacturing and the service sector might in the period around 1990 most strongly have identified their interests (and thus pressured) a move into renewables. To take the main area of current policy activity highlighted in the above comparison, the case of offshore wind might be considered as an example. In the relevant period around the early 1990s, before the divergence of UK and German policies, various sources are clear that it might as readily be thought that the relatively much more advanced status of the UK offshore engineering and services industry, might have justified an expectation than that it would be the UK that was best placed to exploit the massive growth in offshore activity that has since been seen in UK waters. Yet, the prominence in unfolding history of Danish, German, Dutch and Spanish firms in various parts of this UK business shows this national opportunity to have remained unrealised [5].

The complexity of this picture urges, a cautious interpretation with respect to the hypothesis under examination here. Conservatively, then, it must be held to be difficult to be sure which of the two countries might have been expected most likely to make a move to renewables, on the basis of a criterion concerning the readiness and state of development of the emergent industry in each setting. There are arguments that this might initially have been thought to have been the UK. But these risk over-interpretation of history. There are arguments that it was

[5] In a discussion on lessons for UK industrial policy and the UK's notable offshore industrial base that was present in the 1980s, Smith notes that opportunities for transferring UK offshore supply chains to offshore wind development have not been taken, outlining that: *"applying the core principles of the Offshore Supplies Office (OSO) to offshore wind farms… would have seen the UK attempt to build its own supply chain rather than import or subsidise foreign companies…. Instead, the UK content of wind farm developments stands at about 30 per cent"* (286).

Germany that was better placed. But these hinge on unfoldings of later developments, and so risk taking consequences as causes. A prudent conclusion must be that this parameter is indeterminate.

3.6. Relative scales of military-related nuclear activities and interests

3.6.1 Nuclear weapons capabilities

The difference between the UK and Germany regarding nuclear weaponry is stark. Put briefly: the UK is one of only five official nuclear weapons states recognised under the global Non Proliferation Treaty and Germany is not. While Germany hosts US missiles at the Büchel air base it does not itself produce or deploy nuclear warheads. The UK on the other hand is estimated presently to have around 120 operational nuclear warheads (187) with an extensive history of nuclear weapons design, development, production, support and testing – notably involving current dedicated facilities at Atomic Weapons Establishments in Aldermaston and Burghfield. This infrastructure requires a range of specialist nuclear (and other) engineering skills, some of which hold commonalities with skills required in the civil nuclear sector (188). The maintaining of viable nuclear weapons arsenals also requires supplies of a variety of fissile and other specialised nuclear materials – for instance produced by the joint civil-military nuclear enrichment and reprocessing facilities operated by British Nuclear Fuels. Since weapons decommissioning programmes at the end of the Cold War, stockpiles of these materials have grown, effectively reducing demand for ongoing production. Even when attention is restricted directly to nuclear weapons manufacturing, however (rather than materials supply), more than 4000 people are employed across the AWE Aldermaston and Burghfield sites related to building, maintaining and decommissioning warheads (189) There is no such infrastructure in Germany.

3.6.2 Wider Military Nuclear Infrastructures

In order to be considered militarily credible under prevailing attitudes, nuclear weapons require a far larger infrastructure than that concerned simply with production and deployment of the warheads themselves. The UK has effectively contracted out core capabilities around ballistic missile delivery vehicles to the US Trident missile supply chain. But very large scale industrial capabilities are nonetheless still required in servicing and maintaining these technologies – and especially in the design, manufacture, operation and regulation of the fleet of four Royal Navy Vanguard-class ballistic missile submarines (SSBNs) that serve as platforms from which UK strategic nuclear weapons can be launched. With each of these vessels counted among the most complex technological artefacts ever produced (190), the task of sustaining these capabilities is very demanding. For instance, the additional great expense of making the supporting fleet of six Trafalgar and Astute -class attack submarines (SSNs) also nuclear (rather than conventionally) propelled, is itself justified partly as a means to sustain a viable national nuclear submarine industrial base amidst what would otherwise be an untenably sparse production schedule for SSBNs (188,191–194).

So, when all manufacturing and servicing functions and facilities are taken together, the scale of the UK industrial infrastructure required to maintain national military nuclear capabilities is very considerable (195). Those employed in the industry taken as a whole – including major transnational military contractors BAE Systems, Rolls Royce, Babcock and dozens of other companies (196,197) – are variously estimated at around 30,000 (198,199). Challenges in meeting the associated demand for highly specialist skills in research, design, engineering, operations, servicing and regulation is a major preoccupation of Government (192,200). Whilst the UK has committed to a major renewal programme for its military nuclear infrastructures (201) (202), Germany entirely lacks the public spending burden of maintaining national capabilities in this area.

3.6.3 Ceteris paribus proposition

Judgements under this criterion depend on whether prevailing official claims are held to be credible, concerning the notionally separate status of military and civil nuclear industries and infrastructures (203,204). Whatever view is taken, however, the shared industrial and skills base makes the maintaining of military nuclear capabilities at least to some extent a positive aid to the sustaining of parallel civil nuclear infrastructures (205–207). With the scale and significance of associated reinforcing effects a currently topical point at issue (208–211), it can nonetheless be concluded that the presence of major military nuclear programmes in only one of the two countries exercise at least some effects making civil nuclear discontinuation less likely in the UK than in Germany.

3.7 Public attitudes and social movement activity

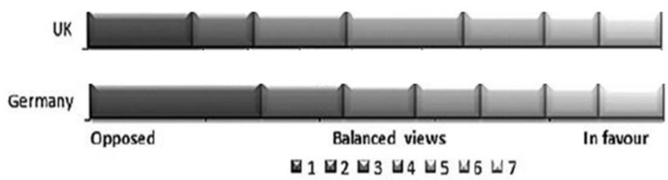
3.7*.1: General public opinion on nuclear power*

Public opinion is a complex multidimensional phenomenon, highly dependent on framing and varying significantly over time. So it is difficult to undertake in the space of this article any in-depth analysis of changes in public opinion over the long time period of nuclear developments in the UK and Germany. What is possible in this section, however, is a review of public opinion surveys during more recent nuclear policy developments as well as during key formative events in the 1980s. Although not exhaustive, this enables a view that is at the same time current and targeted on the most salient junctures.

In these terms, Germany is generally regarded as being distinguished by an especially strongly critical public attitude to nuclear power (212). Indeed, this is often held up as the reason for the remarkable strategic shift embodied in the Energiewende (213). Yet in seeking to gauge how much this understanding is sufficient, it is important to give more nuanced attention to the volatilities in public attitudes over time and under different framings, as well as the diverse ways in which they can be apprehended , articulated – and manipulated – in policy. Since results of opinion polls are so sensitive to encompassing political environments and to ways questions are posed, lack of attention to this dimension could confuse public opinion as a symptom and as a driver of developments.

In general, polls conducted over the past few years do at face value indicate greater public opposition to nuclear power in Germany than the UK (214,215). However, care is needed in order to account for differences over time since the picture contrasts quite interestingly before and after Fukushima. The sense of feasible alternatives and realised agency associated with the unfolding of Energiewende might be seen as a driver as well as an effect of public opinion. Indeed, polls have indicated for many years that only a minority of both the British and German public tend to favour nuclear power. In 2005, for instance, only 22% of respondents in Germany agreed that nuclear power is a relatively safe and important source of electricity, and new plants should be built, compared with 33% in the UK (216). In 2010 the NEA published an extensive report on public opinions on nuclear, charting opposition to nuclear power, as represented in Figure 16 below:

Figure 16: Public strongly opposed to nuclear power ranked 1-7



Source: NEA (217)

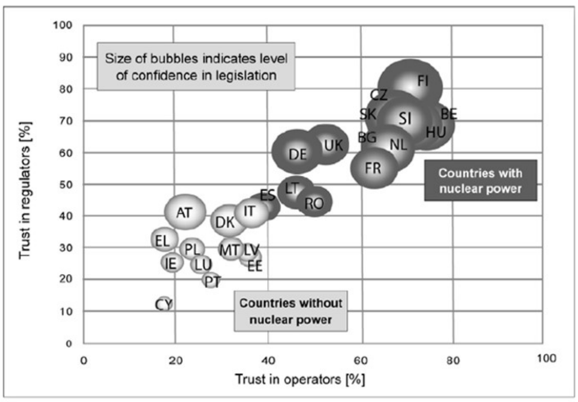
This NEA report also documents the interesting finding that differences between Germany and the UK are even less clear-cut when the issue of climate change is considered. When a prompt is provided to the effect that nuclear power offers a significant climate change mitigation strategy, support for nuclear moves from 22% to 38% in Germany and from 33% to 44% in the UK, leaving the figures differing by only 6 percentage points (217).

It is also important to consider public opinion going right back to the turbulent period of the 1970s and 80s associated with the initial conceiving of the current German Energiewende (186). Though limited in number, opinion polls in both Germany and the UK at the beginning of this period showed generally favourable attitudes towards nuclear (218). This began to change only as the issue became more controversial in the late 1970s. Opinion polls conducted in 1982 showed 52% of respondents in Germany to favour new nuclear power with 46% opposed whilst polls in the UK indicated that only 34% of respondents were in favour with 53% opposed (219). In a poll taken a few months after Chernobyl, 70% opposed nuclear power in Germany and 75% opposed nuclear power in the UK (ibid). So patterns of public opinion in the two countries during the formative periods in which current elite policy commitments first began to develop, give little basis for considering Germany to be markedly more anti-nuclear than the UK – indeed sometimes suggesting the opposite.

3.7.2: Public confidence in the nuclear sector

Within the broader field of public attitudes, one framing of interest concerns relative levels of confidence in the civil nuclear sector (including governmental departments, regulators and the nuclear utilities). Figure 17 below outlines differences across Europe in 2010 (before Fukushima) concerning public confidence in nuclear regulators, operators, and legislators. Notably, Germany and the UK are again quite similar (identified respectively as 'DE' and 'UK'), each featuring in the middle of the range.

Figure 17: Public confidence in nuclear regulators, operators, and legislators



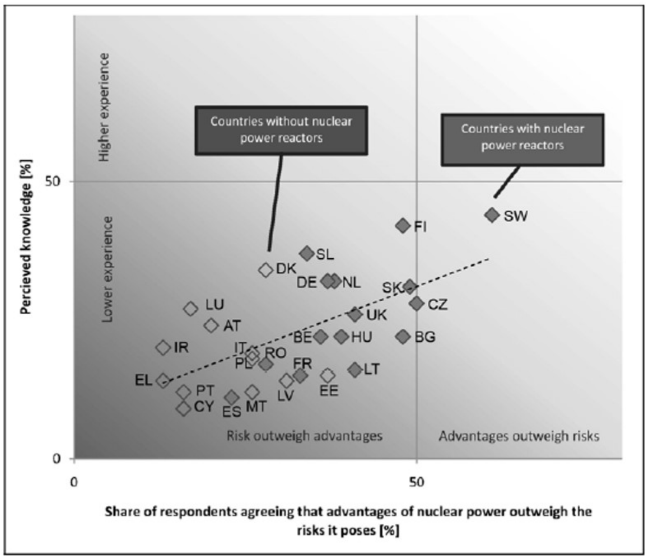
Source: NEA (217)

What can be seen here is that the UK demonstrates only marginally greater levels of public trust in nuclear regulators and operators than does Germany. With confidence in legislation indicated by the size of the bubble, it can be seen that Germany actually displays a greater level of confidence in nuclear legislation – also displaying greater levels of trust in nuclear legislation than in the supposedly most nuclear-supportive context of France. Following Chernobyl in the late 1980s, Peters et al (1987) quoted in Renn (219) found that 60% of Germans surveyed found the Federal Government and its nuclear agencies to be "totally trustworthy".

3.7.3 Public perceptions of nuclear risk

From the point of view of nuclear proponents, another popular way to frame public attitudes to nuclear power, is in terms of perceptions of the acceptability of nuclear risks. Again using NEA data, Figure 18 relates perceived knowledge and perceived risks of nuclear technology in different countries including both countries that have nuclear power as part of their energy mix and some that do not.

Figure 18: Perceived knowledge and perception of risks of nuclear power



Source: NEA (217)

The idea behind this interest of nuclear polling in links between knowledge and risk perception, is the widespread notion that opposition to nuclear power reflects knowledge deficit (220). As stated in the NEA report "…people who feel informed about nuclear safety tend to perceive less risk than those who feel uninformed" (175: 23). A striking detailed feature of Figure 18, however, is the specific comparison between results for Germany and the UK. Germans display greater self-perceived knowledge of nuclear power yet are more concerned that nuclear risks outweigh the advantages. For the UK lower levels of knowledge are associated with a higher proportion of respondents believing advantages outweigh risks. Again it seems that other factors may be at work in shaping public attitudes in these countries – at least as these are measurable in polls.

3.7.4 Scale of social movement action

Both the UK and Germany experienced rapid rises in opposition to nuclear power with the growth of the Green movement and associated NGOs in the 1970s. In Germany the maximal scale of protests were greater and more confrontational. In some German protests violent clashes with the police involved over 100,000 people and a diverse range of German civil society (100,221). The UK also experienced protests against nuclear construction in the 1980s and 1990s. However these were smaller with a maximum size of between 3,000-5,000 (222). In short, although public attitudes in the two countries as discussed above, were not very different, a significantly larger and more active grassroots opposition movement formed in Germany than in the UK.

3.7.5 Intensity of public debate including media mentions

In a study of media coverage of the Fukushima disaster, Wittneben (13), suggests that media reporting both of nuclear issues in general and of this disaster in particular were both more detailed and more continuous in Germany than in the UK. Kepplinger and Lemke, (2015) confirm significantly fewer articles in the UK on the Fukushima accident compared to Germany and far fewer articles discussed Fukushima in the context of domestic nuclear power. They also document that 'left leaning' German newspapers tended to write articles that were critical of nuclear power following the accident. In the UK by contrast, the most widely read article on nuclear issues following the disaster was a piece written by prominent journalist George Monbiot in the left-leaning Guardian, arguing somewhat strikingly that Fukushima had made him 'stop worrying' and 'love' nuclear power (223). It is a continuing feature of the UK when compared with Germany, that mainstream media perspectives on nuclear issues are markedly more favourable than are public attitudes.

3.7.6 Prominence of evidence concerning renewable pathways

Another point that may have a bearing on public attitudes is the relative prominence of academic and policy literatures in each country that discuss future energy scenarios based around the technical potential and cost-effectiveness of renewables and energy efficiency, compared with literatures that emphasise a 'need' for nuclear. In Germany, a significant 1980 report by the Öko-Institut outlined "growth and prosperity without petroleum or uranium" (188, p.3). Albeit less attended to in media and policy debates, however, it is clear that there also exists in the UK an abundance not only of independent studies, but also of official assessments that highlight the cost-effective potential for non-nuclear energy scenarios. Key organisations in this regard include the Energy Technology Support Unit (ETSU), the Watt Committee and the Renewable Energy Advisory Group (162,164). So it certainly is not the case that there was any absence of official literature regarding non-nuclear future energy scenarios in the UK over the time period when German and UK policy began to diverge.

It is true, however, that governmental reports at the highest levels in the UK have emphasised the role of nuclear for future electricity generation. An especially important juncture in this regard is around 2005, when the a striking *volte face* was undertaken by the Government of Tony Blair (110) that has remained central to official policy analyses ever since (224). Only two years before, the 2003 White Paper proposed after a detailed and largely independent energy review conducted by the Performance Innovation Unit (PIU) (225), an effectively non-nuclear energy future based around a shift towards renewables and energy efficiency (226). Whilst more detailed or assertive conclusions under this parameter are inhibited by the scope and complexity of the task, it certainly cannot be concluded that there was any absence of high level policy evidence concerning the viability of non-nuclear energy futures in the UK. What primarily distinguishes the UK and Germany are the policy responses, rather than the evidence itself.

3.7.7 *Ceteris paribus proposition*

This discussion has illuminated grounds for more nuanced questioning of received assumptions that the differences between German and UK nuclear policy are simply due to higher levels of public scepticism in the former than in the latter setting. It appears that other factors may be in play, including the ways these attitudes are framed, articulated with policy making and reflected in mainstream media discourse. Evidence in the public domain is as clear about the potential for non-nuclear energy futures in the UK as in Germany. Overall, however, it nonetheless remains the case that generally greater historic levels of anti-nuclear mobilisation mean that – all else being equal – nuclear discontinuation might be understood to be more likely in Germany than in the UK.

3.8 General national political institutions and elite cultures

3.8.1: Centralised / decentralised political systems

The UK presents a more centralised political system than Germany and one of the most centralised in the OECD (227). Decision-making powers concerning a wide range of activities are all decided at the national level at Westminster, including taxation, economic policies, health care and education. Despite recent varying moves towards 'devolution' of powers to the constituting nations of the UK (Northern Ireland, Wales, and Scotland), English regions retain very little agency in over policy making (228) and the UK remains remarkably centralised. This contrasts strongly with the decentralised German system, where considerably greater political powers are located at the regional level. Since Germany is a federal democracy divided into 16 regions or *Länder,* only Federal Laws apply to the whole of Germany, with other laws being applicable only to the Land in question (229).

3.8.2: Prominence of the Green Party

Constituting the most distinctively critical voice on nuclear power among major parties both in the UK and Germany, the prominence of the Green party offers a useful proxy for the agency afforded to this perspective in elite political cultures. With respect to public opinion examined earlier (Section 3.7) broadly comparable levels of scepticism concerning nuclear power are documented for the UK and Germany (at 38/44%). Yet the proportional representation system makes it much easier in Germany than in Britain for the Green Party to gain parliamentary seats that represent this view. The Greens have been involved in mainstream German political life since the 1980's (186,230), including forming a coalition government with the Social Democratic Party (SDP) in 1998 which was pivotal in implementing the German Nuclear Exit Law of 2002 (97). In a relatively stable recent pattern, 67 of 709 seats in the Bundestag are currently taken by die Grunen, whilst has over the period surveyed here seen only one Green among 650 members of the UK House of Commons.

3.8.3 Ceteris paribus proposition

Given the prominence of the Green Party in particular, and greater decision-making capabilities of different regions in Germany, it could be said that – all else being equal – discontinuation would be more likely in Germany than the UK given the greater plurality of interests and voices that are able to influence policy.

3.9 Qualities of national democracies

3.9.1: Tendency to deliberative-style politics

Building on earlier criteria concerning patterns in public attitudes, political mobilisation and elite policy cultures, this section addresses the crucial but controversial and intangible issue of the quality of the democracy within which these processes play out. If democracy is conceived in the most general terms as 'access by the least powerful to the capacities for challenging power' (231)(48), then questions are raised over the efficacy with which particular institutions and procedures variously help enable or constrain this multifaceted struggle. A number of different aspects bear on this question. Among many efforts to 'rank' and 'compare' different qualities of democracy (discussed below), one pervasive issue concerns the extent to which politics in general is deliberative or confrontational. To what extent do prevailing political processes and discourses enable or obstruct serious questioning of the reasoning behind incumbent policy commitments (232)?

Here, it is a repeated finding that – against a background of much complexity and diversity – Germany displays a generally more deliberative style of politics than the UK. Across all social sectors, Germany tends to afford greater provision for 'negotiation' between different groups (including businesses, trade unions, and various political parties) to produce a shared vision. This contrasts with greater UK tendency towards majoritarian rule

(233). In part reflecting the proportional voting system discussed above, more political parties and a greater frequency of coalitions also condition a need for more deliberative approaches in Germany (234). Here, the UK exemplifies by contrast, an 'adversarial' political system in which coalitions are rare, and notable groups such as trade unions are relatively excluded from high level decision making in situations where they would be regarded in Germany as core to the policy process (235).

This difference in the deliberative style of politics can also be seen in more specific relation to the nuclear issue. The 2002 German Nuclear Exit Law was based around four years of negotiations between diverse interest groups. Following Fukushima, environmental groups played a central role in negotiations around nuclear power through participation in the Ethics Commission (236). In the UK, by contrast, the official review of the implications of the Fukushima disaster was a highly technical process with virtually no input from civil society (237). Even nuclear proponents routinely note that wider UK policy making on nuclear power has repeatedly been characterised not only by a relative lack of consultation, but by a remarkably high level of secrecy (110).

3.9.2 Majoritarian vs consensual democracies

Table 14 stems from research characterising different 'patterns' of democracy (233,234). Here, Lijphart's work identifies a key difference between 'majoritarian' and 'consensual' democracies, which also notably distinguishes Germany and the UK. The 'Westminster model' is used as the archtypal example of a majoritarian democracy in Lijphart's terms, whereas Germany is considered to be more of a consensual democracy. Although of course there are many detailed points of variance and nuance in the on-going transformations in British and German political systems, Lijphart's (166: 7-8) conclusion is that "…consensus democracies scores significantly higher on a wide array of indicators of democratic quality and they also have better records with regards to governing effectiveness".

Table 14: Majoritarian (UK) and consensual (Germany) comparison

	Majoritarian	Consensual
Executive power	Concentration of executive power in single party	Power-sharing in coalitions
Executive-Legislative relationships	Executive is dominant	Executive-legislative balance
Party system	Two party system	Multi-party system
Voting system	Disproportionate representation	Proportional representation
Interest group systems	Pluralist interest groupings with 'free-for-all' competition	Coordinated and corporatist interest group systems aimed at compromise and concentration

Source: Lijphart (234)

3.9.3 Democracy Barometer analysis

Undertaking a wider apppraisal of qualities of democracy in different countries, the Democracy Barometer project examines 30 'established' democracies judging each in relation to 3 'principles' and nine 'functions' including 'freedom' (individual liberties, rule of law, public sphere), 'control' (competition, mutual constraints, Governmental capability), and 'equality' (transparency, participation, representation) (78). When 30 selected countries are ranked under this framework, a stark contrast again emerges between the UK and Germany. Germany is ranked 11th and the UK is ranked at 26 (238). Despite the inherent ambiguities in such an analysis, it seems again that the qualities of British democracy are uncontroversially poorer than those in Germany.

3.9.4 Economist Intelligence Unit analysis

The Economist Intelligence Unit produced in 2010 a further important report that ranks qualities of 167 democracies. In this case, the index is based on five categories: electoral process and pluralism; civil liberties; the functioning of government; political participation; and political culture (239). Under this analysis, Germany is rated 14th and the UK 19th. Again, despite the scope for divergent interpretations, it is difficult to avoid concluding that the UK displays a generally lower quality of democracy than does Germany.

3.9.5 Global Democracy Ranking analysis

The Global Democracy Ranking is undertaken by the Democracy Ranking Association in Vienna. This framing of relative qualities of democracy in 113 countries is again based around several indicators covering aspects including gender balances, press freedom, corruption, political party change, change of head of government, civil liberties, political rights (240). Under this analysis the same picture emerges as under others, with Germany ranked 8th and the UK ranked 13th (241) .

Cetaris parabus proposition

Table 15 below summarises some of the key findings discussed above concerning the variously evidently significantly more positive qualities of democracy widely identified in Germany when compared with the UK. Despite the complexities and multiple dimensions, there seems on balance in these terms, to be generally greater opportunities in Germany than the UK, for less powerful interests to access the capacities to challenge different kinds and aspects of power. If the literatures reviewed earlier in this study are correct, then it appears from the extant contrasting directions of development in the two countries, that nuclear power is better able to thrive under conditions in which democracy is constrained. To the extent this is true, it can therefore be concluded that discontinuation of nuclear power is more likely in Germany than the UK.

Table 15: Summary table of democratic rankings

Rating system	German ranking	UK ranking
Democracy Barometer	11th	26th
Economist Intelligence Unit 2010	14th	19th
Global Democracy ranking	8th	13th

Source: author's own compilation from data above.

4. Discussion of findings

4.1 Summary of Key Patterns

With respect to a wide general literature employing various kinds of 'regime theory' to analyse 'sociotechnical transitions', this study has undertaken an analysis that is highly unusual in its aims at falsification and unprecedented in the detail with which a diversity of parameters are given balanced attention. With respect specifically to studies comparing the circumstances of energy policy in the UK and Germany, this study is also distinctive in seeking systematically to test in a symmetrical way, the relative salience of different potentially formative factors (242). Below is a table summarising how Germany and the UK compare under 29 parameters organised according to nine criteria that are distinguished according to whether they are 'internal' or 'external to the attention of prevailing theory in this field. A short text in each case indicates the broad picture that may be inferred from the discussion so far.

Table 16: Summary table of key findings

Criterion	1: General market conditions	2: Degree of penetration of nuclear in the electricity generating mix	3: The relative strengths of the nuclear engineering sector	4: Availability of national renewable energy resources	5: The scale of national industrial capacities and interests in harnessing renewable energy supply	6: relative scales of military-related nuclear activities and interests	7: Public attitudes and social movement activity	8: General national political institutions and elite cultures	9: Qualities of national democracies
Germany	'Coordinated economy', more state intervention, higher public spending	Higher proportion of electricity generated 25%, greater total amount	Best performing industry in the world on many indicators, best load factor, economies of scale, industry world leaders all aspects of the supply chain, fairly high levels of R&D expenditure on nuclear power	Significantly lower and more expensive overall resource	Significant – industry leader, in wind. Troubled Solar industry. No offshore supply industry	No military nuclear activity	Strong anti-nuclear movements, 100,000 person protests - extensive public debate on nuclear	Decentralised, proportional representation, strong green party, minority parties, 'consensus building', more deliberative	'Consensual', consistently rated as more democratic than the UK in comparative measurements of democracy
UK	'Market economy' neoliberalism, less public spending on R&D	Lower proportion of electricity generated by nuclear (19%) half as much power generated from nuclear as in Germany	Scores badly on most indicators, lower load factor, no industrial strength at many parts of the supply chain, low levels of R&D expenditure	40% wind potential of Europe, cheapest and most abundant wind resource in Europe. Marginally more expensive related to biomass and solar	Less industrial strength, no indigenous turbine manufacturers, significant offshore wind industry, but built by foreign companies. But strong offshore equipment supply industry	Nuclear deterrent. New fleet of nuclear-propelled submarines, Rolls Royce leading UK industrial champion and producer of submarine reactors, trident weapons system	Not large protest movement, NGO presence, often excluded from public debate? Public opinion ambivalent on nuclear	Traditionally Centralised, 2 party system, absence of smaller parties, minimal green party involvement, adversarial, 'expert-driven' with respect to nuclear	'Majoritarian', Rated lower than Germany in comparative measurements of democracy
Ceteris Paribus Proposition	Discontinuation of nuclear significantly less likely in Germany	Discontinuation of nuclear significantly less likely in Germany	Discontinuation of nuclear significantly less likely in Germany	Discontinuation of nuclear significantly less likely in Germany	Mixed picture. Discontinuation marginally more likely in Germany although historical context makes this criteria complicated	Mixed picture, given formal separation of civilian and military nuclear activity the extent to which military nuclear activity has a bearing on civilian nuclear power requires further research. . Discontinuation marginally more likely in Germany	Discontinuation more likely in Germany than the UK	Discontinuation more likely to occur in Germany	Discontinuation more likely to occur in Germany
Locus internal or external to conventional analysis of innovation dynamics in energy-related sectors or sociotechnical regimes	Internal	Internal	Internal	Internal	Internal	External	External	External	External

From the above summary table, a quite clear picture emerges of the comparative implications for reasonable judgements over the relative likelihood according to different criteria of a discontinuation in nuclear power in Germany when compared with the UK. First, the picture is especially stark with regard to considerations that are most central to conventional sociotechnical regime theory. All else being equal, it might be expected under criteria concerning: (i) general market conditions; (ii) nuclear penetration in the generating mix; (iii) the strength of domestic nuclear manufacturing industries; and (iv) the scale and costs of available renewable energy resources; that Germany would be a significantly less favourable environment than the UK, for the successful challenge of nuclear incumbency. As aspects bearing on the relative strength of the 'focal regime/niche configuration' around nuclear power and its directly-associated challenger niches, these are all factors that are relatively 'internal' to conventional theorising on sociotechnical transitions.

The picture is less clear under one other 'internal' criterion (v), concerning strength of potential industrial interests in relation to renewables. This clearly relates to the 'focal regime/niche configuration', but the pattern in this regard is open to divergent interpretations. In one view based on the current situation, the currently relatively large scale of the German renewables industry does seem (counter to the above pattern) correctly to predict discontinuation in Germany rather than the UK. In another view, however, this might be seen more as a consequence than as a driver of the divergent policy orientations. If a longer time frame is considered, going back (say) to the early 1990s, then the similar status of nascent renewables in each country and the much larger scale of UK offshore engineering and services industries, might (given the disproportionate revealed importance of offshore wind as a renewable resource) have led to an expectation that it would be the UK that would move first and most seriously, towards a renewable pathway. As result – and given the need for prudence with respect to hypothesis confirmation – it is difficult to draw a single unqualified conclusion in respect of this parameter.

With respect to 'external' criteria, however, the pattern is again striking. These criteria concern: (vi) the scale of nuclear military activities; (vii) characteristics of formally institutionalised national political culture; (viii) activities of wider social movements, and (ix) assessments of democratic quality. These issues relate more to an entire national economy and polity than to the particular 'focal regime/niche configuration' around nuclear power and its renewable 'challenger niches'. This time, the evidence under each criterion does seem clearly to predict the actual course of development, with nuclear discontinuation being consistently recognised to be more likely in Germany than in the UK. Thus despite the undoubted complexities, uncertainties and ambiguities addressed in this analysis, the overall general pattern may confidently be held to be substantiated in this case, under which criteria that are highlighted in the formal frameworks of mainstream regime theory tend to make incorrect predictions in respect of this particular axis of comparison, whilst criteria that are less prominent in these theories tend to be more correct.

4.2 Towards democracy in sociotechnical transitions

The claim that the most salient aspects in understanding this distinction between German and British nuclear trajectories are generally ‘external’ to a field as diverse and well-established as sociotechnical transitions studies, will inevitably raise queries. This literature is so voluminous, that exceptions can of course always be found – with specific discussions making reference to particular issues that might legitimately be pointed out to relate to those addressed here. Accordingly, a number of studies in this field have made reference to themes relating to the *relevant characteristics of general national political institutions* and *elite cultures* (42,70,250,113,243–249) as well to the *presence and activity levels of social movements* (251–253). Yet it is often a point made in these discussions themselves, that this attention remains relatively marginal or novel in respect of the field as a whole.

The role of social movements in sociotechnical transitions may be considered in more detail in this regard (252,254). Discussions of the German energy transition – including those lying broadly in the field of sociotechnical regime studies, technological innovation systems theory and the multi-level perspective – are of course necessarily typically attentive to the role played by the large national anti-nuclear movement (97,255,256). But a key point here is that – for all that they are acknowledged from time to time – social movements nonetheless remain external to the core ontology of mainstream transition theory that centres around a focal regime (or ‘system’) ’and its immediate challenger niches under a general undifferentiated ‘landscape’.

Conversely, the opposite point must also be addressed, as to whether social movement activity in itself and alone is sufficient to explain the observed difference between Germany and UK? Certainly our research confirms a point noted by others, including in sociotechnical transitions approaches (96) to the effect that Germany’s anti-nuclear movement was larger than that in the UK and played a key role in influencing the transition (213). Yet it must also be acknowledged that the picture is not so simple when attention also extends to other countries including France (221) and Spain (257). These also experienced equally large – and sometimes violent – anti-nuclear mobilisations at different times. Yet these were not as successful as in Germany in halting development of new nuclear build. So the point appears to remain valid, that patterns under this criterion are clearly relevant, but evidently insufficient in themselves.

Likewise, the long-time presence of the Green Party in German politics, also acknowledged here as relevant, might be raised as being perhaps of sufficient importance in its own right (13,258). But here a similar caveat must also be made, in that other cases can be found where the same factor is present but with different results. Finland, for instance, provides an interesting counter-case where prominent participation by the Green Party in political life – including service in government (259) – have left unaffected the status of Finland as one of the few countries in Europe that is still constructing new nuclear power (260). In any case, the prominence of a counter-incumbency party like the Greens cannot easily in any setting, be entirely divorced from the wider issues discussed here concerning ‘qualities of democracy’.

Also in relation to the criterion concerning broad political cultures, the picture identified here does chime with other analyses finding the UK to be distinctive in privileged access by private interests to the inner workings of the nation state (261–263). In this sense, the nuclear case constitutes just one example of close alliances between policy makers and significant lobby groups (16,261,264–266). And this is also a point that has been made by some sociotechnical transitions researchers in seeking to explain counter intuitive developments around UK energy policy (267). But again, this aspect seems unsatisfactory on its own as an answer to the key question as to why nuclear lobbying should so disproportionately be successful in the UK when the national industry is so relatively weak compared to that of other countries? It is this that has led expert commentators to ask “what is the British nuclear lobby”(268) ? Again, the dynamics in play seem broader than can simply be addressed by adding one or other individual analytical criteria, requiring instead a range of considerations.

General qualities of democracy therefore evidently have a distinctive salience with regard to the different directions taken in nuclear policy by Germany and the UK. Here, the post-Fukushima decision in Germany can be seen as part of a longer process of the discontinuation of nuclear including the Nuclear Phase Out Law adopted in 2002 after negotiation between the Social Democratic-Green coalition government and industry (269). Despite a brief episode noted here – swiftly reversed from – in which high-level UK policy appraisal in 2003 markedly favoured a non-nuclear future, the UK never adopted such an official law nor had official targets around nuclear phase out. For many years the UK has had a substantially worse-performing nuclear industry and a more abundant and cost-effective renewables resource than Germany. As time has passed, the technological and economic case for nuclear has significantly weakened by comparison with renewables. This intensifies questions over why it should be the country with ostensibly less substantive grounds for nuclear discontinuity, that made the first move, whilst the country with greater substantive grounds for a transition should remain wedded to the opposite strategy. Whether directly around the nuclear energy industry itself or its wider associations with military nuclear infrastructures, It is difficult to avoid concluding that the influence of some kind of persistent incumbency is a factor here (270). And to the extent that abilities to resist incumbencies lie in multiple forms of democratic struggle, it is similarly difficult to avoid concluding that differences in the respective qualities of democracy across the two countries are also highly salient.

It is for all these reasons, that the findings identified here might be held on balance to address an issue of neglected significance in the field of sociotechnical transitions. Although addressed sporadically in particular areas of regime theory from time-to-time, recognition for the broad importance of general 'qualities of democracy' remains generally very marginal. The issues raised in this regard extend beyond the particular quantitative rankings discussed under the specific parameters examined here, which can only ever offer a highly incomplete and ambiguous picture of a concept as complex and contested as democracy (271–277). In this broader sense, 'qualities of democracy' also implicates all the other 'external' criteria discussed above (78,233,234,240,278). But what is especially compelling under this criterion, is that the overall picture remains so constant, despite the detailed contrasts in the characterising of what might constitute the *particular* qualities of democracy in question.

Here there is a final resonance with one strand of recent analysis in broad transition theory. Jhagroe & Loorbach (75) defend regime theory against accusations that it is insufficiently attentive to democracy, but nonetheless acknowledge the need for further research in this area. Likewise, Hess & Mai (279) associate democracy with 'landscape' processes and argue for further investigation of 'varieties' of factors that determine political capacities to enact sustainable transitions going beyond the focus on 'regime'. Here, they explicitly identify democracy as a key factor which correlates with greater levels of commitment towards policies designed to promote renewable energy. The work of the present authors has further explored particular theoretical (48) and empirical (280,281) implications. Other recent research has pointed towards the need to understand the wider implications of democratic engagement beyond the usual locations in which participation in energy is usually considered taking a systemic perspective on democratic engagement (282,283). It is perhaps with these developments, that the present analysis chimes most strongly.

It is in a related vein, that one final issue can be raised with a bearing on the issue of democracy. This concerns the issue considered here, as to whether developments in the civil nuclear field (at least in the UK) are being driven at least in part by concealed military interests. The findings under this criterion are that the observed comparison between the two countries, is at least consistent with the otherwise difficult to explain pattern of German nuclear discontinuation and British nuclear renaissance. This raises very particular and important implications that are also largely neglected in transitions studies in this sector. Indeed, so important are these, that they are the subject of a separate analysis by the present authors (209)(48). But for present purposes, it suffices to observe that – to the extent that the presence of military interests may exercise a concealed influence on the direction of energy policy – this would in any event be a further instance of the importance of considering general qualities of democracy in the conditioning or resisting of discontinuity.

5.Conclusion

This paper has assessed the background to key recent developments in the challenging and assertion of nuclear incumbency in two countries where these current dynamics are arguably most strikingly contrasting: the UK and Germany. It has done this by means of nine criteria comprising twenty-nine parameters designed on the basis of various literatures to explore key relevant aspects bearing on nuclear incumbency and challenge in these two countries. Despite the complexities, the analysis found a relatively clear picture. On the basis of five criteria concerning dynamics that are most strongly highlighted in mainstream analysis of sociotechnical transitions, it is most reasonably be predicted that Germany would be significantly less likely than the UK to discontinue nuclear power. Yet this is the complete opposite of the observed situation, with Germany hosting a remarkable challenge to nuclear incumbency and the UK experiencing a retrenchment. It is the four criteria that address aspects operating beyond the usual focus of sociotechnical transitions theory (concerning a focal regime/niche configuration articulating incumbents and challengers), that are most in alignment with the observed pattern of developments. It is only in terms of these aspects largely outside 'conventional' regime theory, that it is possible to understand the UK's renewed enthusiasm for nuclear in comparison to Germany's currently ongoing nuclear phase-out.

With analysis focusing on observable policy conditions and dynamics to date, this argument does not rely on assumptions that similar patterns will necessarily continue into the future. And, although caution is required in generalising to other cases beyond the particular industry or national settings focused on here, the refutation of theoretical predictions in only one case, is sufficient basis at least to question theory. So it is significant that the picture illuminated here does not seem satisfactorily explained by reference to any individual criterion – such as public opinion, social movements, concealed military interests or individual progressive political parties. What is relevant instead, are a range of issues that might broadly be characterised as the 'qualities of democracy'. It is on this basis that it is argued that it is crucial to the understanding of sociotechnical discontinuity in this case, that attention be paid to the importance of broader issues than are typically currently attended to in this field, concerning general governance institutions, political discourse and representational processes and practices rather than specific industries, endowments or policy mixes.

This is important, because – despite exceptions – general questions of democracy tend to be somewhat side-lined in mainstream academic analysis in this field using frameworks like those developed in transitions management and the multi-level perspective. And there also arise from this analysis some potentially important practical political implications. If attention fixates unduly narrowly on potential roles for *particular* interventions addressing conditions *within* a specific regime and its contiguous sources of challenge, then this analysis suggests it may lead to an unfortunate neglect for the general importance of wider qualities of democracy in disembedding entrenched interests like those around sociotechnical incumbency (48).

In particular, there may result from this prevalent kind of research an overly concentrated emphasis on relatively specific managerial measures like sectoral missions, targeted instruments, regulatory reforms, operating standards, fiscal adjustments, higher education provision, training capacity, research strategies, protective niches and so on. Without detracting from the potential importance of these kinds of instrumental intervention in many settings, the present analysis underscores a serious question over their sufficiency. What may often be required as well – or even more – than such circumscribed technical policy functions, are entirely more radical and transformative capacities for general political mobilisation and critical challenge (231). Without these general qualities enabling democratic struggle, it may be very difficult to address even the most particular forms of incumbency.

Acknowledgements

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